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THE JOURNAL OF AGRICULTURAL SCIENCE

EDITORIAL.

THERE are at the present time about twenty-five Agricultural Colleges in Great Britain, most of which have grown up during the last ten or twelve years. These institutions are equipped with permanent laboratories and each has its own skilled staff, most of them possess an experimental farm, and all conduct field experiments with the co-operation of farmers Many of the County Councils employ experts who lecture in agriculture and agricultural science and conduct field experiments within the area of the county. There are also a number of men who have recently taken service in India or in our Crown Colonies, and are there engaged in scientific work of an agricultural nature, but who possess no common outlet for the publication of their investigations. Now that the preliminary difficulties of organisation are passed, these workers are at liberty to turn their attention to research in Agricultural Science, and as a result a considerable amount of valuable material of a definitely scientific nature has begun to appear in College Journals and County Council Reports.

College Journals and County Council Reports have however but a restricted circulation, and are very generally neglected outside the immediate area for which they have been written, and as these reports are intended for the general reader and for circulation among farmers of all classes, scientific matter must be presented in a very untechnical form. This often results in the omission of the data necessary for

a critical appreciation of the subject; at the same time scientific papers are lost sight of amongst a mass of other work of purely local or temporary interest.

There is not in this country any general channel for the publication and discussion of scientific papers bearing on Agriculture. These papers are often too technical for publication in the journals of the societies devoted to pure science, and are not sufficiently popular for inclusion in the Journals of the Board of Agriculture or of the leading agricultural societies. The promoters of the present publication therefore consider that the time has come for the issue of a Journal devoted wholly to definitely scientific papers on agricultural subjects, containing:

(1) Original papers. The scope of the Journal will be quite catholic, it will welcome equally papers on biological subjects,—Botany, Zoology, Bacteriology, etc. and on Chemistry, Physics or Geology, provided the question bears on Agriculture The papers must, however, represent original work; reports on the results of demonstration plots, or manurial and variety tests of an ordinary commercial character will not be admitted, nor papers dealing with general farming as distinct from agricultural science.

(2) Occasional *résumés* or critical articles on recent advances in the various branches of Agricultural Science, and notes on the more important papers appearing in British and foreign agricultural journals.

(3) Short notes from contributors who may wish to put on record exceptional cases, analyses, etc., which do not require a full paper.

(4) Articles from Indian and Colonial workers descriptive of soil, climate and other conditions under which agricultural operations are carried on in tropical and semi-tropical countries.

(5) Reviews and discussions. It is hoped that the Journal will furnish an opportunity, lacking hitherto, for the discussion of the work in agricultural science which is being carried on in this country.

The Journal is thus mainly intended to circulate among agricultural teachers and experts, farmers and land agents having an interest in the scientific side of their profession, agricultural analysts, seedsmen, millers, manure manufacturers, etc., in this and other English-speaking countries. The idea of starting such a journal was mentioned and informally discussed at the meeting of the Agricultural Education Association on Dec. 8th, 1903, when about thirty members from various colleges, all engaged in agricultural work, were present, and it met with unanimous approval.

The success of the agricultural sub-section at the Cambridge meeting of the British Association in 1904, also showed that ample material existed for which it was desirable to find a common and permanent means of publication.

The Journal will be issued, as material accumulates, in parts of about 100 royal 8vo. pages Each volume will consist of four parts, the price to subscribers being 15/-. Papers for publication should be sent to T. B. Wood, M A., University Department of Agriculture, Cambridge. Contributors will receive as an honorarium 25 off-prints of their paper free. Additional copies may be obtained at cost price if ordered when the proof is returned.

MENDEL'S LAWS OF INHERITANCE AND WHEAT BREEDING.

By R. H. BIFFEN, M.A.,

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THE investigations to be described below are the outcome of some experiments started in 1900 which had in view the improvement of English-grown wheat The necessity of such work may not be evident to all, so at the outset I will sketch in broad outlines the state of affairs which led me to undertake the task. The fact is generally recognized that the wheats of this country are characterized by their high yields per acre and by the shapeliness of their grain. We can grow on the average over 30 bushels to the acre where the United States grow 14, Russia 10, and the Argentine 7. Yet the acreage under wheat in this country has fallen from three and a-half million acres in 1876 to one and a-half million in 1903, and we now grow approximately only one-fifth of the wheat we consume. Further than this there is good evidence to show that the quality of the grain now grown is inferior to that of twenty years ago[1]. It has been sacrificed to yield, and many of the better class varieties, such as Chiddam, Red Lammas and Rough Chaff, have been more or less driven out of the field by varieties such as Square Head and Rivet, which are capable of giving slightly larger crops of grain and straw. These inferior varieties have now to compete with wheat imported from Canada, the United States, Russia and other countries. The seriousness of the position becomes evident when one finds English wheat selling at 28*s.* 6*d.* a quarter when Manitoba Hard is selling at 35*s.*[2]

[1] Girard and Lindet, *Le Froment et sa Mouture*, Paris, 1903, p. 101.

[2] The figures are a general average—they do not refer to the abnormal prices of this season.

On searching for the reasons of this, the miller tells us that English wheat, even of the better class varieties, is lacking in "strength." We have no single variety which can be compared in this respect with the best foreign wheats. By "strength" he means the capacity of the wheat to produce a large, well-piled loaf[1]. We learn also that English wheat to be utilized at all for bread-making purposes has to be mixed with a large percentage of these strong foreign wheats. The flour of English-grown wheat, alone, will not produce a loaf which is marketable under present conditions, and until the public taste demands dull and heavy bread such wheat can only be used in mixtures.

In addition to this another complication has to be faced. Since the opening up of the wheat-growing districts of the United States and Canada, which in itself has given us an altogether new standard of strength in wheat, the milling trade has to a large extent found its way to the ports. The millers so situated grind the strong wheat brought direct to their mills by sea. The inland miller on buying foreign wheat to mix with our inferior grain has to pay railway freightage, and at present his very existence depends on the fact that he can buy English wheat relatively cheaply at his doors. If, in order to compete with the port miller, he has to use still larger quantities of foreign grain to make up for the shortcomings of our own, then prices must fall still lower or he will be driven out of the field and with him will disappear the market for home-grown wheat. The whole question then pivots on the strength of the grain we can produce. Even a slight increase in quality would go a long way to improving the position both from the farmer's and miller's point of view, for it would immediately widen the market for the home product[2]. Unfortunately we know very little as to what constitutes strength in grain. Many attribute it solely to climatic conditions and state that our problem is a hopeless one. Without discussing the matter I may point out that the work of the Home-grown Wheat Committee of the Incorporated National Association of British and Irish Millers has ruled this view out of court. We can grow strong wheat in this country, but so far the cropping power of the varieties tried has been so poor that the operation has generally resulted in loss. Realizing as I do the complications of the problem I prefer to make no definite statement as to the progress

[1] See also Maurizio, *Getreide, Mehl und Brot*, Berlin, 1903, and *Landw. Jahrb.* Bd. xxxiii. Heft ii. p. 242, 1904.

[2] For further evidence see Hall, "The Quality of English Wheat," *Journ. Farmers' Club*, 1904, p. 123, and *Journ. Board of Agric.* 1904, p. 321.

we have made so far. Several years must elapse before sufficient quantities of the grain of the new varieties can be obtained to subject to the final tests of the mill and bake-house. We can but hope that among the hybrids on the experimental plots are some that will not be found wanting when these trials are made.

At the time of starting these experiments hybridizing was, to quote Lindley, writing over 50 years ago, "a game of chance played between man and plants." Looking at what literature there was dealing with the subject the chances seemed in favour of the plants. The enormous number of varieties of wheat in existence has originated, as far as we have any reliable evidence, in a similar way to the varieties of other plants. Now and then an observant person has detected a plant among the crop differing from its fellows in some character which made it worthy of further propagation. Foremost among such observers was Patrick Shirreff, who discovered many of our older varieties. They have not been built up, as is generally assumed, by a process of accumulative selection, they are rather "mutation" forms[1]. Very few, as far as we have records, have attempted to bring about improvements by cross-breeding. Thus Vilmorin has described the results of crossing together a number of the sub-species of *Triticum sativum*[2]. Rimpau in his classical memoir "Kreuzungprodukte landwirthschaftlicher Kulturpflanzen," has described the results of many years' experimenting in this direction[3]. Some few hybrids were raised in the Minnesota Wheat-breeding experiments[4]. In addition to this more scientific work some seedsmen have also attempted to raise the standard of the varieties of wheat by cross-breeding. In this country the work of the Gartons, which has resulted in the introduction of a number of fresh varieties, characterized on the whole by high-yielding properties, is the best known. Little beyond popular descriptions of their work has, however, been published. An examination of the literature existing at this date, 1900, gave one no clue as to the best methods of attacking the problem. A considerable number of crosses were therefore made indiscriminately, trusting that some few might give improvements in the required direction.

In 1901, however, the whole aspect of the problem was changed by the simultaneous discovery by three independent observers, De Vries,

[1] See De Vries, *Die Mutationstheorie*.

[2] Vilmorin, *Bull. Soc. Bot. France*, T. xxxv. p. 49, 1888; T. xxvii. p. 78, 1880.

[3] Rimpau, *Landw. Jahrb.* Bd. xx. p. 335, 1891.

[4] *Minnesota Agric. Expt. Stat.* Bulletin 62.

Correns, and Tschermak, of the work on inheritance carried out by Gregor Mendel and communicated to the Brünn Society in 1865. This was published the following year, but judging from the fact that only one reference to it is known, and that one gives slight clues as to its value, it was completely lost sight of[1]. As this remarkable paper shows, Mendel focussed his attention not on the plant as a whole but on its single characters, such as seed-shape, colour, etc., and he traces in detail the behaviour of each character in the cross-bred. Then instead of attempting to generalize from the mass of unlike forms appearing in the first generation from the cross-breds he took each individual and subjected it and its progeny to a statistical examination, again character by character. As the outcome of this series of experiments, which in themselves must in future be the model on which experiments on plant improvements are based, he was able to state that the gametes, the egg-cells and pollen grains, are pure with respect to the characters they carry. If for instance a cross is made between a round and a wrinkled pea the cross-bred produces gametes which bear either the round or the wrinkled character, not a blend of the two. Postulating that an approximately equal number of pollen grains and egg-cells carry either one or the other of the characters, then certain numerical relationships observable in the progeny of the cross-breds find a simple explanation. With this clue on reading such works as Darwin's *Animals and Plants under Domestication*, Focke's *Pflanzenmischlinge*, Gartner's *Bastarderzeugung*, one saw, though written from a totally different standpoint, that many facts till then the mysteries of the breeder, found a simple explanation. In fact to those familiar with these special problems further evidence was hardly necessary. One saw still further that many of our current theories of heredity had no real foundations, and that at the first critical test they must fail.

To agriculturists who as a class are continually in touch with the problems of heredity, both in stock and crops, exact knowledge of this kind is invaluable. In the case of our problem, for instance, if wheats behaved in the same manner as Mendel's peas, then the fixing of the chosen forms after the "breaking of the type" was going to be a simple matter requiring merely the test of a single season. and not years of selection and in-breeding. If this were really the case we had prospects of, so to speak, picking out the valuable characters from different

[1] The original paper in the *Verh. naturf. Ver. in Brünn Abhandlungen*, IV. 1865, is almost unobtainable. Translations will be found in the *Journ. Hort. Soc.* 1901, Vol. XXVI. Parts 1 and 2, and in *Mendel's Principles of Heredity*, Bateson, Camb. 1902.

varieties and building up an ideal type. There were possibilities ahead the breeder had hardly dared to hope for. Fresh experiments on the same lines as those of Mendel's were accordingly planned with the object of obtaining definite knowledge as to the behaviour of all the possible characters of wheat on hybridizing. It is true that much could be deduced from Rimpau's work[1] which now became a mine of information, for from his detailed descriptions one could in many cases see clearly how certain of the characters behaved. Here and there, however, it seemed that complications occurred which would entail further investigations, so it was decided to make the experiments as complete as possible, as even confirmatory evidence has its value. During the course of this work two other papers dealing with wheat appeared. One by Spillman is of unusual interest, as it describes experiments carried out on the same lines as Mendel's though the author was at the time unaware of the fact. The results stated afford a striking confirmation of Mendel's laws[2]. The second by Tschermak again serves to confirm Spillman's results More detailed references will be made to these in describing the behaviour of the differentiating characters later.

One older reference is not without interest now-a-days[3]. Le Couteur selected from one of his trial plots a peculiarly vigorous, red, velvet-chaffed (felted) wheat. Among the progeny were plants with red and velvet, red and smooth, white and velvet, white and smooth chaff. He counted the total number of ears, not individuals, and found 200, 21, 86, and 43 respectively of each kind[4]. His original plant was evidently a hybrid, probably a first cross as it was so vigorous, which broke up into the forms we now expect. Le Couteur concluded that this velvet-chaffed red wheat was incorrigible and put forward the following theory to account for the facts. "It might be conjectured that the original or parent ear, having been discovered in a field of mixed white corn, had been impregnated by the pollen of four different sorts of wheat, which the peculiar conformation of an ear of wheat might admit."

For a detailed study of Mendel's laws the wheats proved to be peculiarly suitable. They offer all the advantages for which Mendel originally selected peas. Thus there are a large number of varieties in

[1] *Ibid.*

[2] Spillman, *Science*, Vol. XVI. p. 794, 1902; see Hurst, *Journ. Roy. Hort. Soc.* 1908, Vol. XXVII. Part 4; Tschermak, *Zeits. Landw. Versuchs. Oesterreich*, 1901, Heft II. p. 1029.

[3] Le Couteur, *The Varieties, Properties and Classification of Wheat*, Jersey, 1837, p. 65.

[4] Compare p. 29.

cultivation (I have grown over 200) which are singularly constant; they are autogamous with rare exceptions[1]; the hybrids suffer no diminution in fertility during succeeding generations. In addition to this they have the advantage that they occupy very little space and consequently large numbers can be grown on a small plot of ground. Their chief drawback is that they require to be autumn-sown to give the best results. This leaves only a short period between harvest and seed-time to work through characters, such as those of the grain, which cannot be examined before gathering the crop.

The more important differentiating characters of wheat are as follows:—

(1) The ears are dense or lax. Ears are dense in which the spikelets are so crowded on to the rachis that they overlap one another; the internode length (the length of rachis separating each spikelet) being in such cases about 3·5 mms. Such varieties are often described as club, or club-headed wheats. A typical example is Hedgehog[2]. In lax-eared wheats the ears are generally long and in most the top of each spikelet only reaches to the base of the one immediately above it; the internode length is about 7 mms. Between these dense and lax-eared wheats is a third group with compact ears. These divisions are of course arbitrary and one finds many varieties which cannot properly be classed in either. Each variety, however, is singularly true to ear shape.

(2) The paleæ may or may not be awned. Technically they are described as bearded and beardless. Rivet[2] is an example of the former type, Golden Drop[2] of the latter.

The beardless wheats frequently bear small awns on the paleæ of the spikelets towards the apex of the ear. Such awns are usually short, not exceeding half an inch as a rule, and they cannot be confused with the awns of such a wheat as Rivet, where they are 3 or 4 inches in length and borne on every spikelet.

(3) The glumes may be glabrous or covered with fine, velvety hairs as in the well-known wheat Rough Chaff[2]. The softly hairy forms are sometimes described as "felted."

(4) The colour of the glumes and to a less extent of the paleæ may be red or white. "Red" includes a large number of different

[1] I have never met with a case of natural cross-fertilization, but Rimpau cites a number of undoubted examples.

[2] Figured in Vilmorin, *Les meilleurs Blés*, Paris, 1880.

shades varying from pale red to dark brown, whilst "white" is used to describe any shade from white to pale ochraceous yellows. As a rule the difference between red and white is a sharp one, but in a wet season when the chaff is apt to become discoloured it is often difficult to be sure of the colour. Each variety is quite true to its own particular shade of colour.

More rarely the colour of the chaff is grey as in Rivet wheat. This colour is, at least in my material, very variable. Some ears are dark, others light grey, but in all cases the tint is sufficiently marked to be detected with certainty.

(5) The shape of the glumes provides a number of characters used in classifying the varieties. In some of the sub-species into which *Triticum sativum* has been divided, as in *T. spelta*, *T. turgidum*, *T. durum*, the glumes have a well-marked keel running from the apex to the base. In others, such as *T. vulgare*, the sub-species which includes the majority of the varieties in general cultivation in this country, the keel is only pronounced at the apex of the glume, the base being rounded. I have described these types as "keeled" and "rounded" glumes.

(6) The grain colour is either red or white, the terms again being used to denote the range of colours already mentioned in the case of the chaff. These colours may be associated with a similar colour in the glumes. In the majority of the red-chaffed varieties the grain is also red, but a number of white-chaffed varieties with red grain are in cultivation. The converse case of red chaff and white grain is uncommon, though not impossible.

(7) The shape of the grain is frequently very characteristic, so much so that a grain merchant or miller can often identify a variety from its grain shape alone. The differences in general are difficult to describe clearly though they are readily appreciated after a little practice. In the following account grain shape is only considered in detail where very marked differences exist. In this particular case the grains are either long and triangular in section, or short and rounded.

(8) The characters of the endosperm are again difficult to describe. Those most readily recognized are the hard, translucent, and the soft, opaque types. The former type is met with in the macaroni wheats *T. durum* and *T. polonicum*; the latter is characteristic of most of our commonly cultivated varieties.

The difference is in the main associated with the total nitrogen content of the grain, the macaroni wheats containing a higher percentage than our own varieties.

It would appear also that "strength" is often associated with a hard and translucent endosperm, but further evidence is needed, for the macaroni wheats, for instance, are not "strong" wheats from a miller's point of view. In any attempts to estimate these characters it is essential to reject any ears which are not thoroughly ripened. An unripe ear of the normally soft Rivet wheat may yield hard, translucent grain.

In addition to these characteristics a number of others of less systematic importance will be considered later.

The methods of working are described in some detail below. They are the outcome of several seasons experience with this kind of work and may prove useful to others engaged in similar researches. All the plants are grown under large wire cages as a protection against the depredations of sparrows. This precaution would probably be necessary in most districts, for once sparrows begin to attack the plots they only desist when no more grain is obtainable, and the ordinary methods of scaring seem useless when one is dealing with small plots of wheat. The drawback to the use of permanently fixed wire cages is the difficulty of guaranteeing that no shed grains remain in the soil and come up with the next crop. Working the ground as soon as the crop is off and cleaning again a month later partially meets the difficulty, especially if fowls can be turned into the cages to pick up shed grain. A still more effective plan is to alternate the wheat plots with another crop. I now make use of barley for this purpose as similar experiments are in progress with it.

The actual operation of crossing wheats is a simple one and may be carried out rapidly with a little practice. After many trials I have found the following method the most satisfactory. The ear to be operated upon is selected at the stage when the anthers of the median spikelets are full-grown and beginning to show a slight tinge of yellow, indicating that they will be ripe on the following day. If the ear belongs to a dense or a compact variety alternate spikelets are removed on both sides of the rachis, preferably by tearing them off whole with a pair of forceps. The median florets of about a dozen spikelets are then removed by pressing them outwards and then pulling sharply downwards. In this way only the two outermost florets of each spikelet are allowed to remain. The remaining spikelets are then completely removed. The florets are opened by gently pressing the apex of the paleæ, or if a bearded variety is used by pressing outwards the previously cut-back awn, and the stamens are carefully removed.

Should an anther break during the operation the spikelet is cut off. Pollination is effected by immediately placing a freshly opened anther into the emasculated floret. To secure a supply of these an ear of the variety chosen as the pollen-parent is selected in which the anthers are a full yellow colour. The edges of the spikelets are trimmed off with a pair of scissors so as to open a number of the florets at the apex. The filaments of the mature stamens elongate in the course of a few minutes and push the anthers out of the opening at the apex of the paleæ. They split open and by inserting one top downwards into the emasculated floret a plentiful supply of pollen is showered on the stigma. Before making a fresh set of crosses, or in the event of a stamen from the mother-plant breaking, the forceps are sterilized by dipping them into methylated spirit. There is no necessity for removing the stamens from a floret and pollinating the following day, nor yet of carrying out the operation at an early hour in the morning. If there is any difficulty in securing the varieties in flower at the same date it is feasible to remove the stamens from the earlier variety and protect it from outside pollen. I have never examined the matter in any detail but I have frequently pollinated flowers successfully a week after the stigmas would normally have been in a receptive condition. They were then feathery and unwithered. After pollination the ears are protected by means of folded tissue-paper bags previously waterproofed by soaking in melted paraffin wax. Numerous control experiments have shown that muslin bags are unsuitable for the purpose. An ear for instance on which 12 emasculated florets were left was covered with muslin. Each floret set a grain, pollination having been brought about by wind-borne pollen carried through the meshes of the muslin. The protecting bags may be removed a week after pollination or they may remain on the ears until the grain ripens. If the latter course is adopted the bags should be slit open at the base to allow the water to escape which accumulates, as the result of transpiration, in considerable quantities.

The artificially fertilized grains usually mature a day or two earlier than those naturally fertilized. They are frequently, but by no means always, poor and shrivelled in appearance, but they rarely fail to germinate. Working in this way it is not unusual for 90 per cent. of the artificially pollinated florets to set grain, but much depends on weather conditions. In 1903, for instance, most of the pollinating had to be done on plants sheltered from the rain by tarpaulins. Three per cent. only were successful.

The cross-bred grains are sown as early as possible and given as much space as is convenient in order to secure plentiful tillering.

In the earlier experiments the ears of the resulting plants were enclosed in paper bags or test-tubes to make sure that no extraneous pollen reached them. A series of control experiments showed that this was unnecessary and now they are simply left exposed. The most striking feature of these plants is their unusual vigour. Many have been over 7 feet high when mature, and one could as a rule detect plants resulting from accidentally self-fertilized grains by their lack of vigour when compared with their hybrid neighbours. The grain from the cross-breds is planted in ranks 2 feet long, 12 grains to each, and 8 inches apart. A space of 2 feet between each row of ranks is left as a pathway. By adopting this method the crop is readily cleaned and one can move about among the plants to examine them. Where the cross is between varieties differing only in a single pair of characters a sowing of about a hundred grains is ample to ensure all the possible types occurring among the progeny of the cross-breds. Where one is dealing with more complex cases it is well to sow as much as possible, limiting the crop only by the amount of space and time at one's disposal. Even then the crops are found to increase to such an extent with succeeding generations that much, of necessity, has to be abandoned. In cases where a considerable number of crosses has to be dealt with the entering up of the results becomes no small labour. I have found the following method satisfactory and convenient. A number is assigned to each cross in the notebook, the numbers running consecutively. The hybrid grain is sown and labelled with this number and the characters of the resulting plant noted under it. Each individual of its progeny in turn is assigned a second number, say 8—1, 8—2, 8—3, etc., and its characters are noted on squared paper. The individual numbers are placed successively in a vertical column, and opposite them the characters are noted by a mark in vertical columns reserved for each character, such as bearded, beardless, red, white, etc. In this way a record of each individual is kept with the minimum trouble and the statistical examination is simply effected by adding up the marks in each vertical column. No further numbers are as a rule necessary, as the following generation shows whether the individuals sown under these numbers will breed true or not.

Before giving a systematic description of the hybrids it may possibly simplify matters for those unfamiliar with such work if the story of one or two of the simpler cross-breds and their progeny is followed out step by

step. At the same time it may serve a useful purpose if here and there I indicate the bearing of the facts, as they are elucidated, on conceptions still current among breeders. As a simple example we may choose the case of a cross between Bearded White and Stand-up White (Carter's). The only difference between these varieties is that the former is bearded, the latter beardless. The resulting hybrid (called for convenience F_1) is as beardless as the Stand-up White (Plate I. fig. 1); there is no blending of the beardless and bearded characters resulting in a half-bearded ear. Further, the sex of the parent carrying the beardless character makes no difference, for reciprocal crosses give precisely the same result. I have tested this many times and found no exception to the rule. The fact is worth comparing with the older views on prepotency still current among breeders, who frequently treasure the belief that the female parent determines the constitution of the hybrid, whilst the male imparts such attributes as size and colour, in spite of the fact that even in pre-Mendelian days the evidence against this view was overwhelming[1]. No one can say from the appearance of a hybrid which was the male and which the female parent. It is also considered that the phylogenetically older character is the one which appears in the cross-bred. Speculations as to descent have even been based on this view. One has to admit though that our knowledge of the relative age of plant characters is in most cases very meagre, and there are a number of marked exceptions to this generalization.

Where the beardless plant is the female then the cross-bred has precisely the same general appearance (though more vigorous) as its maternal parent, and we have the well-known phenomenon of "skipping a generation"—so called because the crossing apparently has no effect in this generation, though as will be shown it has in the next. Mendel terms the character which appears in the cross-bred to the exclusion of the other a "dominant" character, and the one which is apparently lost a "recessive" character. Thus the beardless condition is dominant over the bearded. Many pairs of differentiating characters however are not sharply dominant or recessive, as will be shown later. Without thrashing old straw it may at once be noted that the phenomena of dominance are of very secondary importance[2].

The grain resulting from the self-pollination of the flowers of the cross-breds produces plants (the F_2 generation) which are either beard-

[1] Focke, *Pflanzenmischlinge*, Chap. IV. p. 469.

[2] See Weldon, *Biometrika*, I. 1902, Pt. II. and Bateson, *Mendel's Principles of Heredity*.

less or bearded, and a statistical examination shows that they occur in approximately the ratio of three of the dominant to one of the recessive forms, or $3D$ to $1R$. The plants showing the dominant character (lack of beards) are all precisely similar as far as external appearances go, but if the progeny of each individual (the F_3 generation) is examined separately it is found that only one-third of them reproduce the beardless character purely, whilst two-thirds produce both beardless and bearded offspring in the proportion of three of the former to one of the latter The bearded plants of the F_2 generation, that is the recessives, all breed true. If we take a hundred plants at hazard from the progeny of the cross-bred (F_1) they consist not of 75 individuals with the pure dominant character and 25 with the corresponding recessive, but of 25 pure dominants, 50 similar in constitution to the cross-bred as they give the same types of offspring in the same proportions, and 25 pure recessives. We may write this generation then as $D - 2DR - R$. Further generations show that the extracted dominants represented by D and the corresponding recessives R breed true, as far as we can see, indefinitely. The following explanation of the phenomena is offered by Mendel. The two kinds of gametes of the cross-bred bear *either* the beardless *or* the bearded character, *either* D *or* R. If these are produced in approximately equal numbers, then when self-fertilization occurs the chances are that a D pollen grain may meet a D or R egg-cell, giving rise to an embryo, either with dominant characters only or a hybrid, constitutionally represented as D or as DR. Similarly an R pollen grain may give rise to R or DR embryos according as to whether it mates with an R or D egg-cell. No other combinations are possible, so the progeny would be represented by a series of individuals gametically constituted as $D - 2DR - R$. The D and R types breed true, as their gametes carry only dominant or only recessive characters, whilst when the gametes of the type represented as DR, that is the hybrid, are differentiated, then they are segregated into D's and R's, and consequently on self-fertilization the $D - 2DR - R$ series is again produced. Mendel himself tested the point as to the purity of the gametes with respect to the characters they bore by crossing hybrids with the pure dominant and recessive forms, obtaining, as would be expected, in the first case all dominant individuals [$D(D+R)$ gives D and DR], and in the second case equal numbers of dominant and recessive individuals [$R(D+R)$ gives $DR+R$][1].

[1] For further proofs see *Evolution Report of the Roy. Soc.* Pt. I.

We may now consider the results of crossing together two varieties differing in two pairs of characters, such for instance as Rough Chaff and Golden Drop. The former has a white, felted chaff, the latter a red, smooth one[1]. The hybrid (F_1) is rough and red, so that smoothness and whiteness are recessive characters, roughness and redness dominant. For the sake of convenience we may call roughness and smoothness A and a, redness and whiteness B and b. The gametes carry each of these characters pure, and their possible combinations are to be found by combining $A - 2Aa - a$ and $B - 2Bb - b$. These are AB, Ab, aB, ab, $2AaB$, $2Aab$, $2ABb$, $2aBb$, $4AaBb$. There are therefore in F_2 nine types possible, but to the sight only they appear as four, namely, rough red, rough white, smooth red, smooth white in the proportion of $9:3:3:1$. The actual numbers obtained were unusually even, being $45:16:15:5$ in a total of only 81 plants. The rough red types are represented by AB, $2AaB$, $2ABb$, $4AaBb$, since A and B are dominant over a and b respectively. The smooth red types are represented by aB and $2aBb$; the rough white types by Ab and $2Aab$, and the smooth white by ab. This accounts then for the ratio of $9:3:3:1$. The following generation (F_3) shows that the F_2 generation is composed of individuals having the constitution given above. The rough red individuals produced either all rough reds (AB), rough and smooth reds (AaB), rough reds and rough whites (ABb), or rough red, rough white, smooth red, and smooth white individuals ($AaBb$). The rough white individuals either bred true (Ab) or produced rough and smooth whites (Aab). The smooth red individuals either bred true (aB) or produced red and white smooth chaffed forms (aBb), whilst the smooth whites (ab) all bred true.

These results will serve to explain several of the difficulties of the breeder. The F_2 generation, in which the rough red, smooth red, rough white, and smooth white forms appear, represents the well-known "breaking of the type," which we now see is a rearrangement of the characters of the parents[2]. At the same time the fact is explained that the more violent the cross the greater the "variation" produced, since this implies a cross between very unlike varieties, consequently showing many pairs of differentiating characters. It has always been recognized that it is more difficult to obtain "fixed" types from such crosses than from simpler ones. The process may be illustrated by this cross as it is not a complicated one. Four types are distinguishable in the F_2

[1] They have white and red grain respectively, but for the time we will neglect this difference.

[2] In certain cases complications occur: see *Evol. Report*, Pt. I. p. 142.

generation, two of which resemble the parents, whilst two are new, namely, the rough red and the smooth white. A breeder seeking new varieties would probably select the rough chaffed red, a type which is very rare among existing wheats. This type is the commonest in this generation, being represented by nine plants out of every sixteen. Should he select any single individual it might be one of those represented as $4AaBb$, $2AaB$, $2ABb$, or AB. The chances would thus be eight to one against his selecting that represented as AB, the only one which will breed true. On the other hand, should he select promiscuously fine ears here and there, and that is the common method, the plants next season would undoubtedly consist of mixed types. Further selection on the same lines would give the same results, so that one can well believe that certain varieties of hybrid origin have taken years to fix. Where they have been got true it has been chiefly a matter of chance that DR forms have been suppressed. Should the breeder have decided to cultivate the smooth white type ab it would have bred true from the outset. Here then is the converse case of a fixture being obtained at the outset from the "variations" produced on breaking the type. It is generally believed that rigorous in-breeding will serve to fix a type, but obviously enough the in-breeding of a rough red type with a constitution represented by $AaBb$, say, can never make a fixture of it. It is true that most of its progeny would be rough and red, and that fact would be taken as demonstrating that a gradual approach to fixity of type was being obtained, but nevertheless the only fixture would be the type represented gametically as AB.

One other consideration must be noted. In F_2 the rough white and smooth red forms which appear are identical with their parents. Further they may be obtained as fixtures. Similarly from more complex crosses, when Rivet wheat was one of the parents, in the F_2 generation I have picked out a pure Rivet type and bred it true for two seasons. No one so far can distinguish this Rivet wheat from its parental form. In other words, among the progeny of cross-breds the pure parental forms occur—a fact worth noting by the breeders of pedigree stock. If one were dealing with cattle, would such extracted types be allowed a place among the *élite* of pedigree herds in the herd-book? Pedigree to a breeder implies purity of strain, which means that the individual members comprising it produce gametes of the same types only. Yet in spite of their parentage they would be as pure gametically as those boasting the lengthiest list of "recorded" ancestors.

In addition to crosses between varieties differing in two pairs of

characters, three sets of crosses between varieties differing in three pairs of characters have been investigated. The differentiating characters in one case were beardless and bearded (A and a), keeled and rounded glumes (B and b), and felted and smooth chaff (C and c). In F_2 twenty-seven gametically distinct forms are possible, eight of which are fixed, viz., ABC, ABc, AbC, Abc, aBC, aBc, abC, and abc. These fixtures have all been isolated.

An attempt was also made to follow out the progeny of a cross-bred in which four pairs of differentiating characters were united, the three pairs given above and grey and white chaff in addition. Here there should be eighty-one gametically distinct forms of which sixteen would breed true. In the F_3 generation many of the plots produced so few individuals that each type could not be recognized, for where only two or three plants resulted from a sowing of about a hundred seeds it was impossible to obtain the expected number of forms. All the possible fixtures appear to have been produced this season (1904), but in some cases the number of individuals was too small for one to be absolutely confident of the results. Such experiments involve the growing of so many small plots of plants—in this case over two hundred and seventy in the F_3 generation—that they are hardly worth the labour. It would serve no useful purpose to describe each in detail. The results have been recorded throughout, and it is sufficient to say that they are in entire conformity, where the numbers of individuals make this possible, with the results expected from a consideration of Mendel's laws.

Description of Parents.

In the following description of the varieties used in hybridizing, only the more important characteristics are noted. The species *Triticum sativum* (Lam.) has been divided into a number of sub-species, most of which are represented in the varieties described.

Rivet Wheat (syn. Cone or English wheat), *T. turgidum* (Linn.). Ears bearded, felted, compact-dense, square in section, slightly nodding; glumes grey, strongly keeled to the base; grain clear ochraceous red, slightly silky at the apex, starchy and soft; straw long (5 feet), slender, solid or nearly so in the upper internode. Leaves smooth and narrow. It was described by Linnaeus as a distinct species under the name of *T. turgidum*[1]. Now it is generally considered a sub-species of *T. sativum* (Lam.).

[1] Linnaeus, *Species Plantarum*, T. I. Pt. I. p. 478, 1797.

Red King (*T. vulgare*). Ears beardless, glabrous, lax, flattened; glumes straw-coloured, keeled above, rounded below; grain clear ochraceous red, silky at the apex; straw stout, of medium length (4 feet), hollow; leaves broad, scabrid on both surfaces, particularly the upper. The variety was introduced by the Gartons. It is of hybrid origin, Lincoln Red, Michigan Bronze and Waterloo being its parents.

Sunbrown (*T. vulgare*). Ears beardless, compact, square in section; glumes glabrous, red, keeled above, rounded below; grain red; stem stout, of medium length (4 feet), hollow; leaf rough on the upper surface.

White Monarch (*T. vulgare*). Ears beardless, medium lax, squarish in section; glumes glabrous, white, not strongly keeled; grain yellowish white; stem stout, medium length (4 feet or more), hollow; leaves scabrid above. This variety was raised by the Gartons from the following parents: Hunter's White, Victoria Red, and Rivet wheat.

Square Head's Master (*T. vulgare*). Ears beardless, compact, square in section; glumes glabrous, red, keeled above, rounded below; grain red; stem of medium length, stout. The variety is widely cultivated and may be found under many different names

Rough Chaff (*T. vulgare*). Ears medium lax, beardless; glumes felted, yellowish-white in colour under favourable conditions, but liable to be stained during a wet season, grain amber-coloured. My plants frequently produce short awns on the paleæ of the terminal spikelets.

Golden Drop (*T. vulgare*). Ears medium lax, beardless; glumes glabrous, tinged with red; grain red.

Lammas (*T. vulgare*). Ears lax, beardless; glumes red; grain dark red.

Nursery (*T. vulgare*). Ears medium lax; chaff glabrous and red; grain red

New Era (*T. vulgare*). Ears lax, bearded; glumes rounded below, glabrous; grain red. Of hybrid origin, introduced by the Gartons.

Stand-up White (*T. vulgare*). Ears compact, beardless; glumes rounded below, glabrous, white.

Standard Red. Similar to Square Head's Master.

"*Manitoba*" (*T. vulgare*). Manitoba wheat as received in this country is a mixture of a number of distinct varieties. The variety I have used under this name is lax, beardless; glumes white, grain red.

White Tuscan (*T. vulgare*), selected from a commercial sample which produced bearded and beardless plants. Ears lax, beardless; glumes

white, grain white. Early ripening. It has never produced bearded plants on my plots.

"*Devon*" (*T. vulgare*). Variety unidentified but possibly Talavera de Bellevue[1]. Found amongst a crop of Old Hoary in Devonshire. Ears lax, beardless; glumes and grain white.

Hedgehog Wheat (syn. Hérisson, Club wheat, Igel; *T. compactum*). Ears dense, with spreading awns; glumes brownish-grey, glabrous; grain red; straw short and slender.

Polish Wheat (syn. Goose, Diamond wheat; *T. polonicum*). Ears lax, bearded; glumes unusually long (about 20 mm. or more), straw-coloured, glabrous; grain long, translucent, amber-coloured. The plants mature rapidly.

"Minnesota" (*T. durum*), an unnamed variety grown for macaroni-making in the United States. Ears compact, bearded; glumes keeled, reddish-grey; grain amber-coloured, translucent.

In addition to these a considerable number of other varieties have been used as parents, but another season must pass before the results can be recorded Practically all of the characters used in classifying wheats are represented in the above varieties with the exception of the brittle rachis found among the varieties of *T. spelta*. Hybrids with this as one parent are now being raised.

Description of Hybrids (F_1).

Red King ♀ × *Rivet Wheat* ♂. Ears beardless, felted, lax, flattened to about the same extent as Red King; glumes grey, strongly keeled to the base; grain red to red-brown, silky at the apex, translucent; straw very long (6—7 feet), stout, hollow. Leaves broad and scabrid above. The striking vigour of the cross-bred is well exemplified in this case. Not only was the straw of unusual length but the tillering power was equally striking. This of course is largely dependent on the amount of space available for the plant, but grown under similar conditions to the parent plants (in this case 4½ inches from plant to plant and 6 between the rows), the hybrids had at least twice as many stems as the parents. Another noticeable peculiarity was that the lower spikelets, generally some two or three in number, were sterile. This is common in many of our varieties, including Red King, but as far as my experience goes

[1] Vilmorin, *Les meilleurs Blés*.

exceptional in Rivet. The reddish-brown colour of the grain of the hybrid is probably to be attributed to lack of sunshine during the ripening period[1]. The grey colour and also the felting of the glumes was less pronounced than in the parent Rivet wheat.

The reciprocal cross Rivet wheat ♀ × Red King ♂ was also made. After a careful examination of the two sets of hybrids I could find no difference between them.

Sunbrown ♀ × *Rivet* ♂. Ears beardless, compact, the internode length the same as that of Rivet wheat; glumes grey, strongly keeled to the base; grain reddish-brown. Stem stout, long (6—7 feet), hollow; leaves scabrid above.

The ears have therefore a general resemblance to those of the cross-bred Red King × Rivet. On comparing bunches of the two though, the former have a decidedly redder tinge than the latter.

White Monarch ♀ × *Rivet* ♂. Ears beardless, medium lax, squarish in section; glumes felted, grey, strongly keeled below; grain red, but a shade paler than that of Rivet wheat; stem stout, long (6 feet and over); leaf scabrid above. As in the preceding cross-breds, the extent of the felting was variable and might readily have been overlooked in some ears. One other character, occasionally of systematic value, shown in the cross-bred is the "spreading" of the spikelets. This occurs in Rivet wheat where the flowers lie widely apart, but not in White Monarch. The same habit was detected, though not so obviously, in the cross-bred Rivet × Red King.

Square Head's Master ♀ × *White Monarch* ♂. Beardless, lax and flattened; glumes glabrous, red, rounded below; grain red, translucent; stem long (5 feet and over), stout.

The red colouring of the glumes was not quite so intense as that of Square Head's Master[1].

The reciprocal cross White Monarch ♀ × Square Head's Master ♂ gave cross-breds identical in every respect.

Red King ♀ × *Standard Red* ♂. Ears medium lax, glumes red, grain red. The laxness of the ears is slightly greater than that of Red King (Plate I. fig. 2).

Rough Chaff ♀ × *Golden Drop* ♂. Ears medium lax; glumes felted, tinged with red; grain red.

Lammas ♀ × *Manitoba* ♂. Ears lax; glumes and grain red.

Rough Chaff ♀ × *Manitoba* ♂. Ears lax; glumes felted, white; grain red.

[1] That is in 1902. Both 1902 and 1903 were peculiarly bad seasons for work of this kind. They were too wet and sunless. 1904 on the other hand was excellent.

Nursery ♀ × *Rough Chaff* ♂. Ears medium lax; glumes felted, red; grain red.

New Era ♀ × *Square Head's Master* ♂. Ears medium lax; glumes red; grain red.

Red King ♀ × *Stand-up White* ♂. Ears medium lax; glumes white; grain red.

White Tuscan ♀ × *Preston* ♂. Ears lax, beardless; chaff tinged with red; grain red.

White Tuscan ♀ × *Manitoba* ♂. Ears lax; chaff white; grain red.

Devon ♀ × *Hedgehog Wheat* ♂. Ears compact, beardless; glumes brown; grain red and translucent; straw long (up to 5 feet), stout. In general appearance the hybrid resembles the variety Thickset or Hickling (Plate I. fig. 3).

Polish ♀ × *Rivet Wheat* ♂. Ears lax, bearded; glumes felted, varying in colour from pale grey to isabelline white, long but shorter than those of Polish wheat; grains long, but shorter than those of Polish wheat, red, translucent. The plants mature slowly.

The reciprocal cross-bred Rivet ♀ × Polish wheat ♂ was identical in appearance (Plate I. fig. 4).

The grain from selected ears of the cross-breds was sown early, as much of it was poor and shrivelled, partly owing to attacks of rust, partly to the lack of sunshine. Its germinating power was however satisfactory. Even in the seedling stage it became evident that "splitting" was occurring, for among the hybrids with Rivet wheat as one parent there were obviously different types of leaf shape and leaf colour. The vigour of the plants was also very variable, and by the time of ripening many of the weaker individuals had been crowded out of existence by their more vigorous neighbours. By then some of the plants were standing 7 feet high, while some few on the other hand were barely 18 inches. This dwarfing was not due to over-crowding, for several of these lowly plants grew on the open margin of the plots, and in one small plot containing three of them each had over a foot of clear space either side. The dwarf individuals only occurred on plots with a Rivet parentage. The period of maturation was again very variable, some few plants ripening their grain early in August, but the majority not until late in the month or the beginning of September. Taking the plants of this generation (F_2) as a whole they were not characterized by great fertility as in the preceding generation. About 10 per cent. of them were altogether sterile, and many produced only a small quantity of grain. There were a few noteworthy exceptions though; one plant, for instance, produced 1,280 grains.

DETAILED ACCOUNT OF THE VARIOUS CHARACTERS AND THEIR BEHAVIOUR IN F_1 AND F_2.

BEARDLESS × BEARDED.

The beardless condition is a dominant, the bearded a recessive character. This result has already been obtained by numerous workers Rimpau's crosses between Red German bearded wheat and Kessingland, Rivet wheat and Saxon Red wheat, and White Spelt and Red German bearded wheat, were all beardless in the first generation[1].

Further, Spillman[2] and Tschermak[3] have obtained similar results in the first generation and also shown that in the second generation the beardless and bearded plants occur in the usual Mendelian ratio of 3 : 1.

One peculiar case has to be recorded. Vilmorin[4] crossed *Triticum polonicum* and Pétanielle blanche (a white Rivet-like wheat), both of which are bearded, and obtained a beardless hybrid. In this case then the combination of two characters which are recessive appeared to give a dominant. It seems probable though that the hybrid was really bearded, but the awns were shed on ripening This phenomenon is not unusual and I have met with it in the very similar cross-bred Polish × Rivet wheat.

The following hybrids were without exception beardless: Rivet × Red King, Sunbrown × Rivet, White Monarch × Rivet, Rivet × Red King, Bearded White × Stand-up White, Devon × Hedgehog. The next generation (F_2) consisted of beardless and bearded plants. Out of one total of 364 plants 91 were bearded and 273 beardless; in another case 60 were bearded and 27 beardless; in another 34 and 11; in another 58 and 16; in another 15 and 4. Taking all the plots together this gives 440 beardless to 149 bearded, or a ratio of 2·95 : 1, a sufficiently near approximation to the expected ratio of 3 : 1.

Among this number were a few plants with the short terminal awns, up to half an inch in length. As this occurs in the awnless parents such plants were reckoned with the beardless forms. In the succeeding generation F_3 the bearded forms, *i.e.* the recessives, without exception bred true, whilst the beardless forms either bred true, *i.e.* pure dominants, or gave a mixture of bearded and beardless plants A statistical

[1] Rimpau, *loc. cit.*

[2] *Science*, 1902, Vol. XVI. p. 794.

[3] Tschermak, *loc. cit.*

[4] Vilmorin, *Bull. Soc. Bot. France*, T. XXXV. p. 49, 1888. See also T. XXVII. p. 73 and p. 356, 1880.

examination of two of such plots from Rivet × Red King gave a total of 94 beardless to 32 bearded plants. Among a total number of 163 plots from this cross (F_3) 88 produced a mixed offspring, corresponding to the $2DR$ of $D - 2DR - R$ in F_2. The numbers are a little wide of the expected ratio 2 : 1, but owing to the small number of plants which survived the winter (1903) one could not always be certain that a plot with say only half-a-dozen beardless plants represented a pure extracted dominant or a hybrid, for with so small a number the bearded (recessive) forms might well have been missing.

VELVET CHAFF × GLABROUS CHAFF.

The felted or velvety character is dominant, the glabrous recessive.

This is deducible from Rimpau's crosses between Rivet and Square Head wheat, Mainstay and Square Head, Early Red American and Mainstay, and from a number of natural crosses which he has recorded. Vilmorin has obtained similar results in the case of a Spelt crossed with Blé à duvet (Rough Chaff), and Spillman and Tschermak have again proved that in the second generation three velvet chaffed wheats are produced to each smooth chaffed plant.

Nevertheless some difficulties occur on a further examination of this pair of characters. Thus Rimpau's cross between Saxon wheat (glabrous) and Rivet wheat (velvet) is quoted by de Vries[1] as an example of a character usually recessive being dominant.

On referring to the original the hybrid is found to be described as "vollig der Vaterpflanze" (*i.e.* Saxon Red) No special mention is made of any particular character and further no hairs can be distinguished in the figure of it (Taf. XIII. Nr. 13). Rimpau also makes no mention of the felted character in the hybrids resulting from the union of Rivet and Red German Bearded wheat, though in the case of Red American × Mainstay he describes the felting as being slight but distinct.

In the following hybrids the glumes were felted:—Rivet × Red King, Sunbrown × Rivet, White Monarch × Rivet, Red King × Rivet, Rough Chaff × Golden Drop, Rough Chaff × Nursery, Manitoba × Rough Chaff, Polish × Rivet. On comparing them though there was found to be this difference. In those with Rivet parentage the felting was very variable in extent, but where Rough Chaff was one parent

[1] De Vries, *Mutationstheorie*, Band II. p. 40.

it was constant and as fully marked as in that parent. None of the Rivet cross-breds were as strongly felted as the Rivet itself, and many would have been classed as glabrous unless they had been examined under a lens.

Perfectly glabrous ears did not occur. The gradation from felted ears to glabrous was so gradual that it was impossible to divide the series into strongly and slightly felted individuals.

An examination of my stock of Rivet wheat showed that this particular character was a singularly constant one, so that no explanation could be found by assuming parental variation.

The case then is obviously different from any of those met with by Mendel in peas. If the characters are represented as *I* and *II*, and the hybrid by a, a diagram such as:—

$$\frac{a}{I}\text{———————————————————}II$$

would represent the character *I* as being regularly dominant, while such a case as the above would have to be represented as:—

$$\begin{array}{ccccccccccc} & a & a^1 & a^2 & a^3 & a^4 & a^5 & a^6 & a^7 & a^8 & \\ I & & & & & & & & & & II \end{array}$$

the individuals nearest *I* being strongly hairy.

I am inclined to think that Rimpau's hybrids would be included in this second group, and then it would be quite intelligible that the slight hairiness, say of a^7 or a^8, should have escaped notice, particularly as at that time no special attention had been called to the necessity of examining the hybrids character by character.

In the next generation (F_2) felted and glabrous individuals occur:—Rough Chaff × Golden Drop, 63 felted to 23 glabrous; Manitoba × Rough Chaff, 373 : 140; Rough Chaff × Nursery, 262 : 79. The totals for these three plots therefore give the ratio of 698 : 242, or approximately 3 : 1.

In the cases where Rivet wheat was one parent the following figures were obtained:—Rivet × White Monarch, 23 : 17; Sunbrown × Rivet, 49 : 22; Red King × Rivet, 151 : 77; or a total ratio of 223 : 116[1].

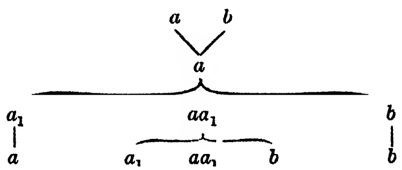
The separation was variable where Rivet wheat was the felted parent, for plants occurred with ears which were strongly felted

[1] The figures for Polish × Rivet and its reciprocal have not been ascertained yet.

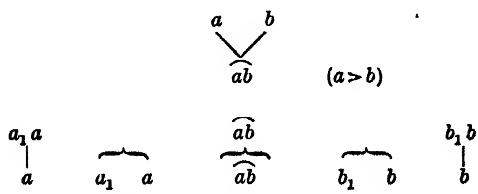
No figures can be given at present to show the relative frequency of the grey and white forms, as the examination of this particular set of plants has had to be deferred.

Red and White Chaff.

The fact that the red colour of the glumes is a dominant and the white a recessive character is evident from a considerable number of cases already known. A typical example is found in a cross made by Vilmorin between a white spelt and a red wheat which produced (F_1) a red spelt-like wheat. Spillman's experiments also point to dominance of red over white, but both Rimpau and Tschermak have described examples in which a mixing of the parental colours occurred. In the following hybrids the ears were red or reddish: Red King × Square Head's Master, Red King × Standard Red, White Monarch × Square Head's Master and its reciprocal, Rough Chaff × Golden Drop, Lammas × Manitoba, Devon × Hedgehog (brown). Where the full red colour was not developed the result is almost certainly to be explained by the lack of sunshine in 1902 and 1903, for in all the cross-breds grown in 1904 the colour was as clear and as well developed as in the parents. At the same time the possibility is not excluded that we again have to deal with irregular dominance similar to that shown by the grey colour. The difficulty is recognized by Tschermak, who concludes that this pair of characters does not show simple dominance and recessiveness. If Mendel's scheme is represented as



he represents the behaviour of this colour pair as:



the hybrid showing characters belonging to each parent, and sub-

sequently splitting in a more complex fashion than those with strictly Mendelian characters.

To test this point several hundred plants of the F_2 generation of each of these red cross-breds were raised. In 1903 the season proved unfavourable and finally only those of Rough Chaff × Golden Drop were harvested. The ears from these plants were then compared with Golden Drop (the red parent) and Rough Chaff (the white parent) and, in spite of the fact that the former would be considered a very light coloured type of a red wheat, there was no difficulty in separating them out into 64 red and 21 white plants, that is, the usual 3 : 1 ratio. At the same time the red colour of the ears frequently differed from that of Golden Drop, sometimes being darker, sometimes lighter, but this variation was so frequently found among ears from one and the same plant that it was impossible to group them, as individuals, into plants showing the pure red and plants showing the intermediate colour.

One further test of the accuracy of this counting was possible by comparing the distribution of the red and white among the velvet and smooth chaffed wheats. Neglecting five plants which were poorly developed and stained, the remaining 81 were composed of 5 smooth white, 15 velvet white, 16 smooth red, and 45 velvet red individuals, that is, the expected distribution of:

$$9VR \quad 3VW \quad 3SR \quad 1SW.$$

In 1904, under far more favourable conditions, the F_2 generation of Lammas and Manitoba was raised. It consisted of 329 red individuals to 115 white. The red coloration was practically constant, and no intermediates occurred. It would seem therefore that the dominance of red over white is pure in these cases.

RED AND WHITE GRAIN.

The red colouring matter of the grain is confined to the testa of the seed and shows through the thin, transparent ovary wall. The white wheats do not possess this colouring matter, so red and white grains form an easily recognizable pair of characters. Imperfect ripening tends rather to exaggerate the difference, for the red grains are then usually liver-coloured, whilst the white grains become only a shade yellower. In the hybrid plants (F_1) of Rough Chaff × Golden Drop and Rivet × Polish wheat the grain was invariably of a clear red colour, so

perfectly distinct from the amber colour (so-called "white") of Rough Chaff and Polish wheat, that a single grain could be picked out from a sample of them. In the next generation (F_2) the plants of Rough Chaff × Golden Drop were separated into red- and white-grained by matching them against the grain of their parents, Golden Drop and Rough Chaff. Six doubtful plants were neglected, leaving a total of 80; 60 of which had grain matching that of Golden Drop, 20 that of Rough Chaff. As a further test 200 ears taken from separate plants of Manitoba × Rough Chaff (F_2) were examined They gave 154 red to 46 white-grained forms. Segregation into red and white grain also occurs in Rivet × Polish wheat (F_2) but no statistics are as yet available. There are also indications that dark red is dominant over light red, for the progeny of the cross-bred Lammas × Manitoba, the former of which has very dark grain, consists of dark and light grained individuals. The evidence therefore points to the fact that red is dominant over white and the splitting in F_2 is pure.

Keeled and Rounded Glumes.

This pair of differentiating characters occurs in the crosses between Rivet wheat with Red King, White Monarch and Sunbrown. In all cases the hybrids (F_1) showed the keeling of the glumes in undiminished intensity. In the following generation (F_2) keeled and rounded individuals occurred in the ratio of 171 : 58, 37 : 17, and 30 : 10. In F_3 one plot only, of Rivet × Sunbrown, was examined for this pair of characters. It contained 84 keeled and 26 rounded individuals. The totals are therefore 322 keeled to 111 rounded or a ratio of 3 : 1.

Lax and Dense Ears.

In practically all the varieties I have made use of there has been some slight difference in the length of the internodes between the spikelets, though the crosses between Rivet and Polish, and Devon and Hedgehog wheat are the only ones which afford a really well marked difference between the parents in this respect. Rimpau's[1] cross between early Red American and Square Head wheat, and Vilmorin's[2] between Polish wheat and Pétanielle blanche show that the lax type is dominant over the dense. In one set of Spillman's[3] crosses the length of the

[1] *loc. cit.* [2] *loc. cit.* [3] *loc. cit.*

hybrid ear is intermediate between that of the parents, and in the following generation lax, intermediate, and dense ears occur in the ratio of 1 : 2 : 1.

As a typical case we may take the cross between Square Head's Master and Red King with average internode lengths of 3·2 and 4·6 mms. respectively. The hybrid ears were laxer than the lax parent, averaging 4·8 mms. (Plate I. fig. 2).

The increased length of the hybrid ears is probably simply a correlation with the increased height of the hybrid plants, it being a general rule that dense ears are associated with a short straw, and lax ears with a long straw.

In the second generation (F_2) at the first sight it appeared as if the splitting into lax and dense ears was most irregular, owing to the fact that many of the plants produced long, dense ears, or long, lax ears, or the corresponding short forms. It was found impossible to sort the ears into the two types by inspection only, so a typical ear from each of one hundred individuals was measured, the number of spikelets counted and the average length of the internodes estimated. This gave a result of 78 lax to 22 dense individuals, 4·6 mms. and over being considered as lax and measurements below that as dense. The figures are suggestive of the three to one ratio though they depart rather too widely from it.

Among the lax-eared individuals the exaggeration of the character was frequently met with, 24 plants having an average internode length of over 4·6 mms., while one ear showed as high a figure as 5·0 mms. No ears were found with shorter internodes than the dense parent, though from inspection only it appeared that this would be the case.

In the case of Rivet wheat (3·6 mms.) × Polish wheat (6·6 mms.) the hybrid internodes averaged 5·8 mms. The F_2 generation consisted of plants with internode lengths ranging from 3·1 to 6·8 mms. A large number were measured by Mr W. L. Balls and the figures obtained point to a segregation into dense, intermediate, and lax in the ratio of 130 : 362 : 179 or (?) 1 : 2 : 1. The results stated are provisional, for the matter is still being investigated. The first generation of Devon × Hedgehog wheat has produced ears which are intermediate between their parents in respect to the lax and dense characters. It resembles therefore the hybrid described by Spillman which produced the lax, intermediate and dense ears in F_2[1]. The F_2 generation of this has still to be grown.

[1] Spillman, *loc. cit.*

HOLLOW AND SOLID STRAW.

The cultivated varieties of *T. vulgare* show in all that I have examined a hollow straw while Rivet wheat (*T. turgidum*) has a thin straw, especially below the ear, which is practically filled with pith—a fact well known to Jethro Tull, who describes it as "having its straw full of pith like a rush." The two types are so distinct that one often hears the Rivet straw described as "goose-necked" by agriculturists.

When wheats showing the two types are crossed the resultant hybrid always has a thick, hollow stem similar to that of the *T. vulgare* variety. Rimpau's illustrations do not show this particular pair of characters as the ears are cut off too closely, and I can find no reference to it in the literature I have consulted though from the technical point of view straw structure is almost as important as yield of grain.

That the hollow type is dominant over the solid is however evident enough from an examination of the Rivet series of crosses.

In the following generation (F_2) splitting occurs and a number of very different types of straws occur, some being thick and solid, slender and solid, thick and hollow, thin and hollow, ribbed and ribless, rough and smooth. These were sorted out into hollow and solid individuals, with the result that 170 of the former were found to 56 of the latter. This pair of characters then splits in the usual Mendelian ratio.

A further examination of the straws gave a sufficient reason for the multitude of forms occurring in this generation, it being found that numbers of other characteristics could be detected.

These are best seen in transverse sections of the stems, taken for the sake of uniformity from the middle of the uppermost internode in each case. The two types are afforded by Rivet wheat and Red King. In the former the outline of the stem is strongly ridged, the ridges being formed by massive girders of sclerenchyma running out from the large innermost bundles. The parenchymatous tissue of the pith either completely or almost completely fills the innermost part of the sections. In Red King the stem outline is nearly circular, its regularity being only broken by slight undulations formed for the most part by sclerenchyma girders from the smaller vascular bundles. Girders are also formed from the larger innermost vascular bundles. The epidermis, particularly on the ridges, bears numbers of short, stiff bristles. The parenchyma of the pith forms a thin layer only, the stem being hollow. The sclerenchyma girders are far less massive

throughout than those of Rivet wheat, and those from the innermost ring of bundles are no more developed than those from the smaller exterior bundles. Sections of the stem of the hybrid generation (F_1) are more strongly ridged than those of Red King owing to the greater development of sclerenchymatous tissue, the pith is only slightly developed, and the short, stiff epidermal hairs, absent in Rivet wheat, are present on the ridges.

The development of the girders is not, however, as marked as in Rivet wheat. Reciprocal crosses, and crosses between Rivet wheat and Sunbrown, show the same characters. From this it would appear that a hollow pith and solid pith, bristly and smooth epidermis, angular and circular stem sections, massive and slight sclerenchyma girders are differentiating pairs of characters, the first mentioned in each case being dominant. The last pair belongs to the "more or less" order, and the question might be raised as to whether the increased amount of sclerenchyma is not to be correlated with the increased vigour of the hybrids.

The numerous types of stem are, therefore, the expected result of shuffling a number of pairs of characters together. An anatomical examination of a number of chosen stems resulted in finding the majority of the predictable types, but the task of grouping the whole set statistically has still to be undertaken. The fact that the one pair so examined splits in a Mendelian ratio makes it probable that the remainder of these anatomical characteristics do so also.

The same types of splitting have also been observed among the heterozygotes (*DR*'s) in F_3 and a number of the more promising forms have been saved to breed from later.

ROUGH AND SMOOTH FOLIAGE.

From the descriptions of the hybrids it is clear that the rough type of leaf is dominant over smooth. Sections of the leaves of Rivet wheat, the smooth parent, show that the upper surface in particular is covered with slender hairs. Similar hairs, though relatively less abundantly, occur on the leaves of Sunbrown, White Monarch, and Red King, but here they are mixed with short, stiff bristles, similar to those occurring on the stem. The presence of these bristles accounts for the roughness of their foliage. The foliage of the F_1 generation of Rivet, crossed with either Red King, Sunbrown, or White Monarch, invariably bore short,

stiff bristles interspersed with the longer silky hairs, showing that here again their presence is a dominant character, their absence a recessive.

Broad and Narrow Leaf-shapes.

Where a wheat exhibiting markedly broad foliage is crossed with one possessing narrow leaves the hybrid bears the broad type of leaf, as is shown in the single cross of Red King and Rivet wheat, and its reciprocal. In the next generation (F_2) broad and narrow foliage occurs together with leaves difficult to place definitely in either class. The numerical relation of these classes was investigated in one case with the result that 57 individuals were grouped as broad, 67 as narrow, and 110 were neither one nor the other.

Assuming that these 110 individuals were normal, and that the foliage was fully developed—the plants were not crowded together—the figures suggest a ratio of 1 : 2 : 1.

Probably the leaf colour affords yet another pair of characters, some varieties being a deep bluish-green others a glaucous green. Indications of this have been seen in several cases, but the matter has not been investigated.

Time of Ripening (Late and Early).

The hybrids between Polish wheat and Rivet wheat afforded an example of this particular pair of characters. Polish wheat is tender, and to avoid danger from frosts it has to be sown in this country about the middle of March, it then grows rapidly, rushes through its flowering and ripening stages, and may be harvested by the first week in August Rivet wheat, on the contrary, is hardy, and when autumn sown is usually about the last of the commonly grown varieties in this country to ripen. On my plots during 1903 it did not ripen until the third week in August. Definite dates are difficult to give, because in thinly sown plots the plants tiller considerably, and the smaller ears of the side branches may be a fortnight later in ripening than the ears of the main branches

The grains obtained as the result of the crosses made in 1902 were sown on March 15th in order to avoid the risk of damage by frost, as there was the possibility of tenderness being a dominant character, and

a few grains of Polish and Rivet wheat were put in alongside to serve as controls. The Polish wheat showed signs of ripening early in August, and by the third week of the month the ears, even on the side tillers, were thoroughly matured. The hybrid plants, however, pushed their ears through the sheaths from five to seven days later, and produced no ripe grain until September 17th. The side tillers were not harvested until a month later, and even then they were not thoroughly ripened. The late sown Rivet wheat ripened the main ears on the plants late in September, but the ears of the side tillers were not ripe when the plots were finally cleared away on October 20th. The time of ripening for the hybrids is a little earlier than that of the late parent Rivet wheat.

In the next generation F_2 (sown Feb. 26th) all the plants flowered simultaneously; the ears pushed through the sheaths on June 11th, and the stamens were ripe on June 18th. The Polish wheat sown on the same date also flowered at this period, but the Rivet wheat was twelve days later. The first signs of ripening were noticed on July 10th. By July 30th many plants were ripe, others were almost ripe, others dead green. At this date the Polish wheat was ripe, whilst the Rivet was quite green.

A statistical examination was then made, the following being the criteria used for grouping the plants:—Ripe, glumes and straw yellow, grain hard; half-ripe, awns yellow, glumes beginning to turn yellow, straw yellowish-green, grain soft; unripe, green throughout. The results were 103 ripe, 210 half-ripe, 100 unripe. A second plot[1] gave 84 ripe, 171 half-ripe, 79 unripe. The figures clearly indicate a ratio of 1 : 2 : 1.

On August 3rd a small plot of 74 individuals, the survivors of 200 autumn-sown grains, contained 56 ripened plants and 18 unripe, so that an examination at this stage would have pointed to the fact that early ripening was a dominant character. The true state of affairs is of course shown by the other statistics. It is worth noting that the time of ripening was in no way correlated with the habits of the plants. Individuals resembling Polish wheat were either early, late, or intermediate in their ripening periods, and the same is true for the Rivet-like individuals.

Probably similar results could have been obtained with the other Rivet hybrids, though there was not so marked a difference in the ripening

[1] W. L. B.

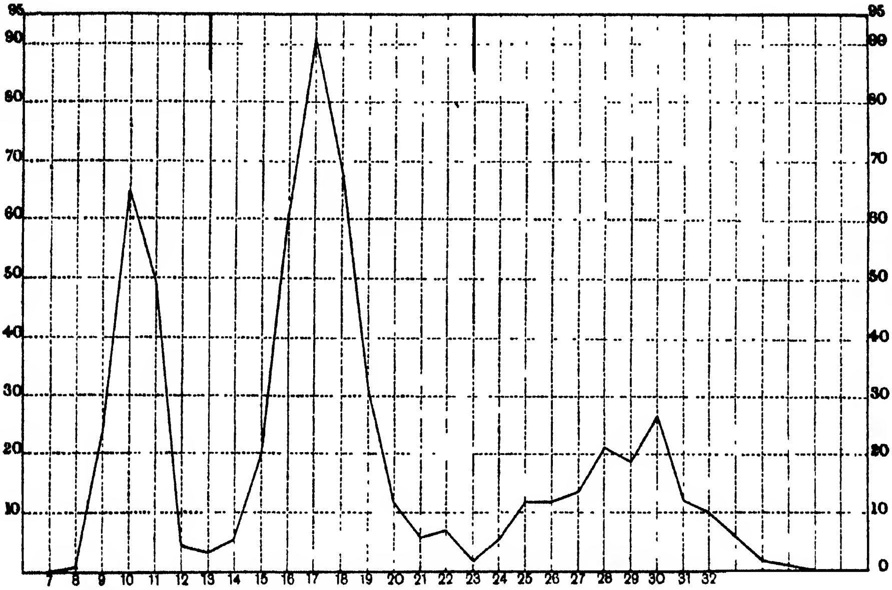
periods. In both the F_2 and F_3 generations of these hybrids great differences were observed between individuals in this respect. This season (1904), for instance, ripe ears were gathered on August 7th from Rivet × Red King (F_3), whilst other plants were not fully ripe at the end of the month. This points to an intensification of characters similar to that already described in the case of the grey colouring of the glumes. The case is of interest as it affords an example of a pair of constitutional as opposed to morphological characters.

LONG AND SHORT GLUMES.

These characters are represented in the cross between Polish and Rivet wheat and its reciprocal. A somewhat similar cross was made by Vilmorin between Polish wheat and Pétanielle blanche, a variety of *T. durum* The cross-bred (F_1) produced glumes which were intermediate in length between those of the parents. The same result occurred with my cross-breds, the glumes again being of an intermediate size in both cases. The average glume length of 21 plants was 17 mms., that of the parents 28 and 9 mms. respectively. The peculiar loose appearance of the ears of Polish wheat caused by the glumes standing away from the rachis in an irregular manner was not represented in the cross-breds. Their more compact manner of growth resulted in square ears more like those of Rivet wheat (Plate I. fig. 4).

The F_2 generation at first sight seemed to consist of individuals with glume lengths varying from one extreme to the other. The long, intermediate, and short types were obviously present, but one continually hesitated as to whether any particular individuals should be classed as short, or intermediate or long. The glume lengths of a number of plants were therefore measured with direct-reading callipers, the measurements being taken from the base to the shoulder of the glume. In each case the third glume from the base of the ear was taken to be the standard. This was considered necessary as the glumes of the spikelets towards the apex of the ear are smaller than those towards the base, and preliminary measurements pointed to this as the best position for giving representative results. The glume lengths ranged from 8 to 35 mms. These were plotted on squared paper, the lengths along the base line, the number of individuals vertically, with the result that the curve so obtained was found to be sharply divided into three distinct portions. The three separate curves corresponded with the small, the intermediate, and the large glumes. On

counting the number of plants represented in each curve they were found to be 149, 304, and 142. A second series of measurements on the reciprocals gave the numbers 205, 432, 188. The figures are a fair approximation to the ratio of 1 : 2 : 1, showing that on the separation



Glume length curve of 595 individuals of Rivet × Polish wheat, F_2.

of the gametes of the hybrid into those carrying the long and short characters where long meets long we have the long type of glume, similarly where short meets short the short type, and where long meets short, as in the original operation of artificially crossing, the intermediate type is produced.

The curves are of interest from another point of view. That corresponding with the small glumed type is steep and shows a range of 5 mms. (from 8—13 mms.), that corresponding to the large type is flattened with a range of 12 mms. (from 23—35 mms.), whilst the intermediate curve is compounded of the flat and steep curves with a range of 10 mms. (from 13—23 mms.). The steep and flat curves correspond broadly with those of the parents. Curves plotted with the glume lengths of Rivet wheat are steep, those with the glume length of Polish wheat flat, for in this sub-species the glume length varies over a considerable range. No detailed figures are given here as the matter is one which is worth further investigation.

Long and Short Grains.

These characters have also been examined in the Polish × Rivet wheat hybrids and their offspring. In my material the grain lengths are 10·1 and 7·2 mms. respectively. Before describing the results it is necessary to have a clear idea of the structure of a grain of wheat. It must be realized that we are dealing with a fruit in which the carpel wall is fused with the testa of the seed proper in such a manner that the seed cannot be separated from it. The study of the grain characters is further complicated by the fact that the endosperm of a grain resulting from an artificial cross is as much a hybrid as the embryo itself, for this endosperm arises from the definitive nucleus which has previously been fertilized by one of the two generative nuclei of the pollen tube The grain resulting from a cross is therefore partly hybrid (the endosperm and embryo) and partly a portion of the female parent (the testa and carpel wall), or to put the matter crudely the endosperm is a generation ahead of the grain coats[1]. Presumably the shape of the grain is determined by the endosperm

The hybrid grains of the reciprocal crosses were, as is usually the case, slightly shrivelled, but the shapes and colours corresponded with those of the female parents, those borne on the Polish parent being longer and more slender in shape than those on the Rivet parent and also paler in colour. In the following generation (F_1 of the plants) the grains produced by the reciprocal crosses were identical in appearance. They were relatively broader than those of Polish wheat and longer than those of Rivet wheat—the length being on the average 9·0 mms. Such grains could properly be described as intermediate between those of the parents. There was no segregation into the long and short types in this generation (Plate I. fig. 5).

The generation raised from these grains (F_2 of the plants, F_3 of the endosperm) consisted of individuals with short, intermediate, and long grains. The distribution of these will have to be considered later when I have found an opportunity to work through the whole crop. It may however be stated that the small grains only occur among the plants with small glumes, the large grains among the plants with large glumes[2].

[1] No actual proof of this has been given in the case of wheat, but Guignard has shown that this double fertilization occurs in maize.

[2] Some 200 individuals examined.

Similar cases though not sufficiently distinct for accurate estimation have occurred in the crosses between Rivet and Red King and a variety of *T. durum*.

This failure to segregate in the expected generation appears to afford a parallel to the case of the indent peas quoted by Tschermak and again investigated by Bateson[1]. No satisfactory explanation of the phenomena can be afforded, but when one takes into account the distribution of the different types of grain mentioned above it seems clear that the maternal plant characters—in this case of size of the glumes—in some way directly influence the seed characters in each generation.

HARD AND SOFT ENDOSPERMS.

I have used these terms in describing endosperm characters which really represent relatively high and low total nitrogen contents respectively, as the texture in itself affords a ready approximate method of judging this particular character. I recognize that the method is not an infallible one, but it is the best we have at present. The hard endosperms are usually translucent and glutenous, the soft ones opaque and starchy. Polish and Rivet wheat are examples of these two types. The endosperm of the grains produced as the actual result of the cross was hard in both sets of crosses. No stress can be laid on this fact though, as the ripening was not normal, the grains being shrivelled, and shrivelled grain is generally of this texture. The grain of the next generation (F_1 plants with F_2 endosperm) was all hard, whilst that of the parents ripened alongside as controls was hard in the case of Polish and soft in the case of Rivet wheat. Here and there a grain which was partially opaque (starchy) in patches occurred, but these were altogether confined to late-ripening side tillers. The number of such grains was not determined, but it was certainly less than 1 per cent. Their occurrence may safely be neglected, for grain from the side tillers of Polish wheat showed the same appearance. The expected segregation into hard and soft grain did not occur in this generation, but it occurs in the F_3 generation (F_2 of the plants), enough of which has been examined for me to be sure of this fact, but not enough to afford any statistics as to the numerical relationships existing between the two classes. A preliminary examination of the nitrogen contents as

[1] Presidential Address, Zoological Section, British Association Meeting, 1904.

determined by Kjeldahl's method, has given the following results. Polish wheat 2·3—2·5 % N.; Rivet wheat 1·8 % N.; hybrids 2·45, 2·3, 2·16, 2·04, 2·01, 2·0, 1·99, 1·94, 1·84, 1·83, 1·81, and 1·72. The figures are too small to base any conclusions on, but they seem to point to a segregation into high, intermediate, and low nitrogen contents. That segregation does occur is illustrated by the following fact. I sent two samples of the grain from an F_2 generation of a cross, in which these particular characters were not so distinct as in the case under consideration, to Mr A. E. Humphries, of Coxe's Lock Mill, for his opinion on them. Their parentage was not stated, yet he came to the conclusion that the grains were samples, not from cross-breds, but from the two original parents which he named[1]. Further evidence hardly seems necessary. 200 ears taken at random gave 152 hard to 48 soft-endospermed forms, or a ratio of 3 : 1.

Immunity and Susceptibility to the Attacks of Yellow Rust.

It is generally recognized that certain varieties of wheat are far more susceptible to the attacks of rust (as a rule *Puccinia glumarum*) than others, and from time to time suggestions have been made that more immune varieties should be sought for in order to minimize the losses annually caused by the attacks of this fungus[2]. Our knowledge of what determines immunity to the attacks of fungi is so slight that practically nothing has so far been achieved in this direction. One had no ideas of the lines on which such investigations should proceed. Some years of experience with numerous varieties not only of wheats but of barleys, swedes and potatoes have convinced me that these varieties can be grouped into classes according to their capacity for resisting various diseases, and that broadly speaking the grouping for one season holds with reasonable accuracy for other seasons, whether the disease is epidemic or only slight[3]. This being the case it follows that some varieties inherit a constitution making them capable of withstanding the attacks of certain fungi, others one making them susceptible. Other

[1] The difference between these types of endosperm is too subtle for me to attempt to describe. They are the slight differences which can only be appreciated by those who continually handle grain.

[2] As far back as 1815, Thomas Andrew Knight suggested that varieties proof against the mildew (or rust) should be raised. *Pamphleteer*, Vol. VI. p. 402.

[3] Cf. Eriksson, *Die Getreideroste*.

workers have come to the same conclusions. Thus Farrer states that the susceptibility to rust is hereditary in wheat[1]. If this is the case it is important to know what would happen when immune and susceptible varieties are crossed. To test this point Michigan Bronze was crossed with Rivet wheat and *vice versâ*. This latter wheat is as a rule fairly immune to yellow rust, and I used a strain selected two years previously (in 1899) which was peculiarly so. Michigan Bronze is probably the most susceptible wheat to yellow rust in existence. So badly are the plants attacked on my plots that I can hardly obtain enough grain each season to sow again.

Six plants of this parentage were raised. They were at first strong and vigorous, but by the middle of June (1902) the whole of their leaf surface was covered with rust pustules, which spread until the glumes and even the awns were orange with it. There was nothing to choose between the reciprocals in this respect either. On harvesting, these plants produced three grains which failed to germinate—a fact which will indicate the severity of the attack. A second series of crosses, those between Red King and Rivet wheat and the reciprocal, were examined from the same point of view. Red King is again very susceptible to yellow rust, possibly because Michigan Bronze is one of its parents. These hybrids were also badly rusted and indistinguishable in this respect from Red King growing alongside. They yielded, however, some 300 grains from which 260 plants were raised in 1903

The season was favourable for such work, the rust epidemic being even worse than in the preceding year. It appeared as early as March 16th, but only spread slowly until the last week in May. By June 15th the epidemic was judged to be at its climax and the extent and percentage of disease were observed. The result was 78 plants almost free from disease, 118 showing a few pustules only, and 64 badly diseased. The extent of infection though increased steadily, and a second count on June 29th reduced the number of relatively immune plants to 64, whilst the remaining 195 were infected, for the most part badly. Now the ratio 64 : 195 seems to be too close an approximation to the ratio 1 : 3 to be a mere accident, and taken in conjunction with the fact that the F_1 generation was so badly attacked it is fair proof that susceptibility and immunity are definite Mendelian characters, the former being the dominant one.

This experiment has an important bearing on the "mycoplasm"

[1] Farrer, *Agric. Gazette of New South Wales*, 1889, Vol. IX. p. 131.

hypothesis put forward by Eriksson to account for certain facts with regard to epidemics of rust which need not be described in detail[1].

The main point of the hypothesis is that "a latent germ of disease is inherited from the parent plant," the parent being the *mother plant.* For a time this germ exists in "une symbiose intime" with the host plant, then under certain more or less defined external conditions the fungus protoplasm develops, giving rise to the parasitic rust.

This hypothesis is difficult to accept and still more difficult to disprove[2]. It was not until Eriksson actually demonstrated the "mycoplasm" and mycelium arising from it that this became possible. Then an elaborate histological examination carried out by Marshall Ward[3] showed clearly that what Eriksson had taken to be the developing fungus protoplasm consisted in reality of the haustoria pushed into the host-cells by the intercellular mycelium of the rust. Eriksson working in collaboration with Tischler[4] after further research admits the identity of his first "mycoplasm" with the haustoria, but now states that the granular contents of certain otherwise normal cells in the leaf of the wheat are the symbiotic blend of fungus and host-protoplasm[5].

Assuming then the truth of this hypothesis, and excluding for the time being all chance of external infection, the plants are immune if they inherit no "latent germs," and susceptible if they do so. Where external infection is possible the fact is not altered that immune plants inherit none since no disease occurs. If then A is immune and B is susceptible, A ♀ × B ♂ should be immune and B ♀ × A ♂ should be susceptible, since the "latent germs" are transmissible by the maternal parent[5]. The reciprocal crosses where Rivet wheat is the immune parent and Michigan Bronze or Red King the susceptible parent show however that this is not the case, for A ♀ × B ♂ and B ♀ × A ♂ are both highly susceptible. Here again then the "mycoplasm" hypothesis does not conform with the facts observed, but breaks down precisely where the student of heredity would expect it to. To bring it into conformity with our present knowledge of the subject it would have to be assumed that the "latent germs" can be handed on by the male parent as well, that is by way of the generative nuclei!

[1] Eriksson, *Ann. d. Sc. Nat.* T. XIV. p. 107, 1901.

[2] For negative evidence see Klebahn, *Die wirtswechselnden Röstpilze*, p. 79, 1904.

[3] Marshall Ward, *Proc. Roy. Soc.* Vol. LXXI. p. 353, 1903, and *Phil. Trans.* Vol. CXCVI. p. 29, 1903.

[4] Eriksson, *Comptes Rendus*, 1903. Cf. *Archiv für Botanik*, Band I, p. 143, 1903.

[5] *Ibid.* and *Rev. gén. de Bot.* 1898, T. X. p. 44.

This conception of immunity and susceptibility as definite constitutional characters throws some light on other aspects of the immunity problem. The most important of these is its bearing on the attempts to correlate immunity with morphological characters. By way of an example, one not infrequently finds it stated that thick-cuticled wheats or potatoes are more immune than those with thin cuticles. Where serious attempts have been made to trace any connection between such characters and immunity, as in the case of Marshall Ward's work on the Bromes[1], none whatever can be found, and one is driven to conclude that the differences are intraprotoplasmic. Now certain well-marked differences between the leaf characters of the varieties experimented with have already been pointed out, and at first sight it might well have been that immunity was dependent on one of these[2]. Nevertheless among the progeny of the hybrids (the F_2 generation) it was found that immunity by no means depended on any of these characters, leaves of the Red King type being as free from disease as those of the parent Rivet, whilst leaves of the Rivet type were as frequently badly rusted. The immunity simply depended on the luck of the shuffle.

The F_3 generation has in its turn given results which confirm those of the preceding generation. From the 260 plants composing it 163 plots were raised in 1904. One hundred and eighty-five were sown originally, but the conditions at seed-time were far from suitable and 21 failed entirely. Many plots only contained a few plants. At the end of May it became obvious that the relatively immune plants of the former season (*i.e.* the recessives) were breeding true in this respect, for each plot stood out sharply as a green patch among the orange plots of badly rusted individuals (dominants and hybrids). On counting out the plots 49 were relatively free from rust, and 114 were either rusty or contained an excess of rusty individuals. The separation into plots representing the extracted dominants and the mixed individuals was not attempted owing to the small number of plants on some of the plots, which would probably have led to confusion. The figures are very wide of the expected ratio, but the error is on the right side, for it is only reasonable to assume that the mortality would be greatest among the progeny of the most susceptible individuals in F_2 which in consequence of disease had produced seed of poor vitality. The failures should then be reckoned

[1] Marshall Ward, *Anns. Bot.* Vol. XVI. p. 233, 1902.

[2] Cf. Hartig's *Diseases of Trees*, Engl. edit. 1894, p. 171, where the cultivation of a woolly-leafed willow hybrid is recommended in place of its glabrous-leafed parent in districts where *Melampsora hartigii* is abundant.

with the badly rusted plots, which raises the number to 136 and gives a ratio of 136 : 49 or 2·8 : 1.

A further examination of four of the plots containing both classes of individuals gave 149 rusty to 48 relatively rust-free or a ratio of 3·1 : 1, figures which again agree with one's expectation on the assumption that the liability is dominant over immunity.

Further experiments are now being carried out with a more immune wheat than Rivet, which I have only recently obtained.

Thick and Thin Glumes.

This particular pair of characters has not been specially investigated. I was struck by the fact, while rubbing out the ears of the F_2 generations of crosses with Rivet parentage, that many shed their grain readily whilst in others the grain was so tightly gripped in the florets by thick outer glumes that it was difficult to remove the grain on rubbing. Extreme cases were met with in which the spikelets remained altogether closed and on rubbing the rachis broke into fragments. An examination of the parents then showed that the Rivet wheat had thicker glumes than the other varieties, a fact which had escaped my notice earlier. These plants with closed spikelets and brittle axes had for the most part lax ears, but the corresponding compact forms were present The one point of interest associated with them is that the closed spikelet and brittle rachis are the distinguishing characteristics of *T. spelta*. As a matter of fact the plants were so spelt-like that several people with a special knowledge of wheats have had no hesitation in referring them to this sub-species. Further, practically all of the commoner types of spelts were represented among the thirty individuals occurring in Red King × Rivet (F_2), and the smaller number in Rivet × White Monarch. There were beardless, bearded, grey, red, and white varieties (Plate I. fig. 6).

Six years ago this would have been a striking demonstration of "reversion" to a more primitive type. Now one has become somewhat suspicious of these reversions and one examines them more critically than hitherto In the first case we have no evidence which conclusively shows that *T. spelta* is a primitive type. It has probably been considered as such, solely on account of this habit of breaking the rachis for "seed" dispersal, which is common in many of the wild grasses. Further than this I see no possibility of advancing in this direction.

One other possibility had to be considered. Red King and White Monarch are already complex varieties raised by the Gartons and it might have been that spelt wheats were used in building them up, which in some way or other had split off again. Mr John Garton has kindly given me their pedigree, which contains no spelt parentage[1].

Such considerations as these led me to take the view that these individuals were spelt-like but not true spelts, that they had originated simply as the result of a fresh combination of characters represented in the parents, the thickness of the glumes having been intensified just as the grey colouring has been shown to be. In support of this view it has to be mentioned that individuals occurred among the non-spelt-like forms which had thinner glumes than those of the thin-glumed parents, that is an intensification of the thin character. If the glumes increase in thickness then it becomes more difficult for the developing ovaries to push them open, and a point is reached at which the spikelets remain closed. Such intermediate stages do occur. The spelt-like appearance of the ear would thus be accounted for. The brittleness of the rachis is more difficult to explain, for it would seem that a fresh character, one not found in either parent, has appeared. Here again though difficulties arise, for one finds individuals in which the rachis is only slightly brittle, others in which it is more brittle, so that the new character has made its appearance in a series of steps, not outright. On the whole it seems to me most probable that brittleness is a character correlated with closed spikelets, as "seed" dispersal would be impossible without it. Since harvesting the F_2 generation in 1903 I have carefully compared these spelt-like ears with the corresponding varieties of *T. spelta*, and I have been still further struck by their similarity in general appearance. At the same time, whilst admitting that from a systematist's point of view they may be identical, they are not so to one who is accustomed to the more minute distinctions between varieties met with in agricultural practice. The two points of difference which appeal to me most are: (1) that the texture of the grain is that of our English varieties—it would not yield the fine pastry-flour so characteristic of spelts; and (2) the rachis of the true spelt is more brittle than that of the spelt-like ears among the Rivet crosses. The F_3 generation of these spelt-like wheats showed the same types of segregation as the other hybrid forms. The bearded, white individuals (*i.e.* recessive in

[1] It is perhaps worth pointing out here that in spite of the complexity of the parentage of these two varieties they are indistinguishable from pure varieties even on further crossing—a fact Mendel's work would lead one to expect.

both characters) bred true, the beardless either bred true or threw bearded and beardless individuals, the velvet-chaffed either bred true or threw velvet and glabrous, and so on, but the closed spikelets and brittle rachis were retained in each case.

General Conclusions.

Summing up the results obtained up to the present we find that for each pair of unit characters segregation occurs in such a way that the results obtained agree with those expected on the assumption that the gametes are pure with respect to the characters they carry. The characters either separate out in the F_2 generation (or in the case of certain seed characters in the F_3 generation) according to the usual ratio of $3D:1R$, when one of the pair is dominant and the other recessive, or when the dominance is imperfect as in the case of grey over white glumes, or in the ratio of two intermediates to one of each of the pair where neither character can be considered as dominant over the other.

These characters may be grouped as follows:

A. Those showing pure dominance and thus resembling those described in peas by Mendel:

Dominant	Recessive
Beardless ears.	Bearded ears.
Felted[1] glumes.	Smooth glumes.
Keeled glumes.	Round glumes.
Lax ears.	Compact ears.
Red chaff.	White chaff.
Red grain.	White grain.
Thick and hollow stem.	Thin and solid stem.
Rough leaf surface.	Smooth leaf surface.
Bristles on stem.	Smooth stem.
Large sclerenchyma girders associated with an angular stem outline.	Small sclerenchyma girders and an almost circular outline.
Hard, translucent endosperm.	Soft, opaque endosperm.
Susceptibility to the attacks of Yellow Rust.	Immunity to Yellow Rust.

Where investigated in detail the ratio of $3D:1R$ has been found in F_2 for these pairs of characters.

[1] Where Rough Chaff is the felted parent.

B. Those showing irregular dominance; in F_1 some individuals show one of the pair in almost full intensity, but in others it may be hardly visible:

Felted glumes[1].	Glabrous glumes.
Grey colour of the glumes.	Red or white glumes.

In the F_2 the segregation is normal as in the preceding group.

C. Those in which there is no dominance of either character and the F_1 is intermediate between the parents in respect to the following pairs:

Lax and dense ears.
Large glumes and small glumes.
Long grains and short grains.
Early and late habit of ripening.

On segregation two of the intermediates occur to each of the pure characters, a ratio corresponding to $D : 2DR : R$.

Mendel's laws of inheritance apply to morphological, histological, and constitutional characters, and one can probably recognize as many pairs of characters as there are minute differences between the varieties experimented with. The various shades of red in the grain, the various degrees of laxness of the ears, etc., are each represented by character units.

No indisputable case of "reversion" has occurred. Where hybrid varieties of known parentage are crossed with other varieties no indications of the parentage of these hybrid varieties, excepting the characters they themselves show, have been met with.

Any desired combination of the characters represented in any two varieties can be obtained "fixed" in the first or at the most the second generation from the hybrids.

In addition to the characters described above a number of others dealing with fertility, hardiness, differences in the aleurone layer, etc. are being investigated.

I take this opportunity of acknowledging much kindly assistance given me whilst this work was in progress; in the first place by my wife, who carried out much of the preliminary work of hybridizing and aided me in sorting out each generation and recording the characters of the individual plants; and also to Mr A. E. Humphries, who besides

[1] Where Rivet wheat is the felted parent.

providing me with many varieties has given me much valuable advice whilst dealing with the endosperm characters and other more technical matters with which I am not particularly familiar.

EXPLANATION OF PLATE I.

Fig. 1. (*a*) Stand-up White, (*b*) Bearded White, (*c*) the hybrid (F_1) Stand-up White × Bearded White, showing that the beardless condition is dominant over the bearded.

Fig. 2. (*a*) Red King, (*b*) Standard Red, (*c*) Red King × Standard Red. The hybrid (F_1) is lax eared, and the internode length slightly exceeds that of the lax parent Red King.

Fig. 3. (*a*) Hedgehog, (*b*) Devon, (*c*) the hybrid Devon × Hedgehog, this is intermediate between the parents in respect to the laxness of the ear. Note the short awns at the apex of the spike. They occur, not infrequently, in Devon wheat.

Fig. 4. (*a*) Rivet, (*b*) Polish, (*c*) the hybrid Rivet × Polish. It is intermediate in laxness and glume length between its parents.

(a'), (a^2) dense and lax small glumed types of F_2,
(b'), (b^2) dense and lax large glumed types of F_2,
(c'), (c^2) dense and lax intermediate glumed types of F_2.
In (b') the awns have shed partially.

Fig. 5. Grains (*a*) of Rivet, (*b*) of Polish, (*c*) of the hybrid Polish × Rivet, F_1 plant generation.

Fig. 6. Beardless, spelt-like wheats showing the keeled glumes and closed spikelets. They are white, red or grey in colour.

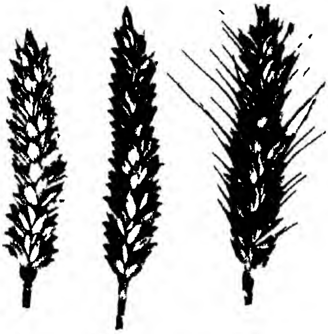


Fig 1.

Fig 2.

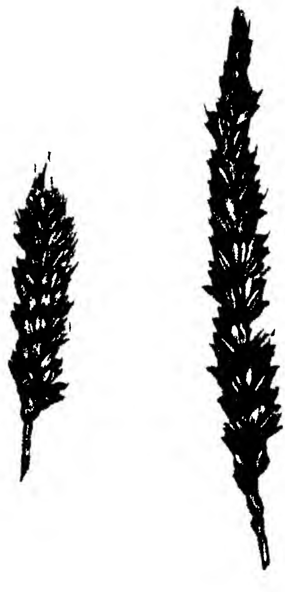
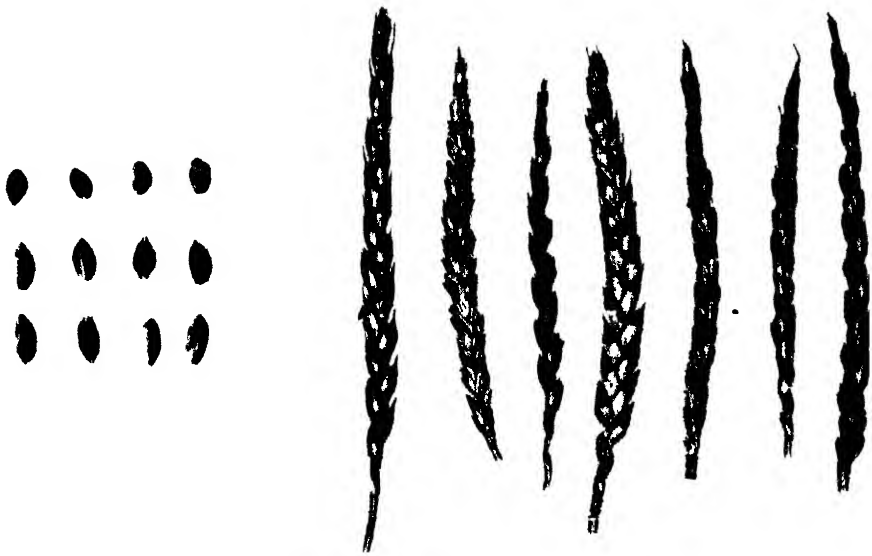


Fig 4



THE INFLUENCE OF POLLINATION ON THE DEVELOPMENT OF THE HOP.

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In general the hop is diœcious. Sometimes, however, in gardens of the Bramling variety, hills are met with from which bines arise bearing both male and female flowers. Such monœcious plants are rare.

The male flowers: The inflorescences bearing the male flowers are much-branched cymose panicles, arising either from the axils of the main stem or from the axils of the lateral shoots.

Each flower is about a quarter of an inch in diameter, and consists of a five-leaved sepaloid perianth, opposite which are five stamens with short filaments and long anthers, which liberate their pollen by longitudinal dehiscence (1, 2, 3, Fig. 1).

The female flowers: The female flowers occur in definite inflorescences (strobiloid spikes) which are borne on branches arising directly from the leaf axils of the main stem itself, or from the axils of the leaves upon lateral shoots produced by the main stem. These inflorescences give rise to the hops of commerce. Each female flower is very minute and consists of a cup-shaped perianth, partially surrounding the superior ovary, which contains a single ovule and which is surmounted by two long stigmas covered with elongated papillæ (4, 5, Fig. 1). At this stage (as a rule early in July) the hops are said to be "in burr." After the stigmas or "brush" of the young hops drop off there is a rapid growth of the bracts of the strobile, giving rise to the fir-cone shape of the mature inflorescence (7, Fig. 1). The bines are now said to be "in hop."

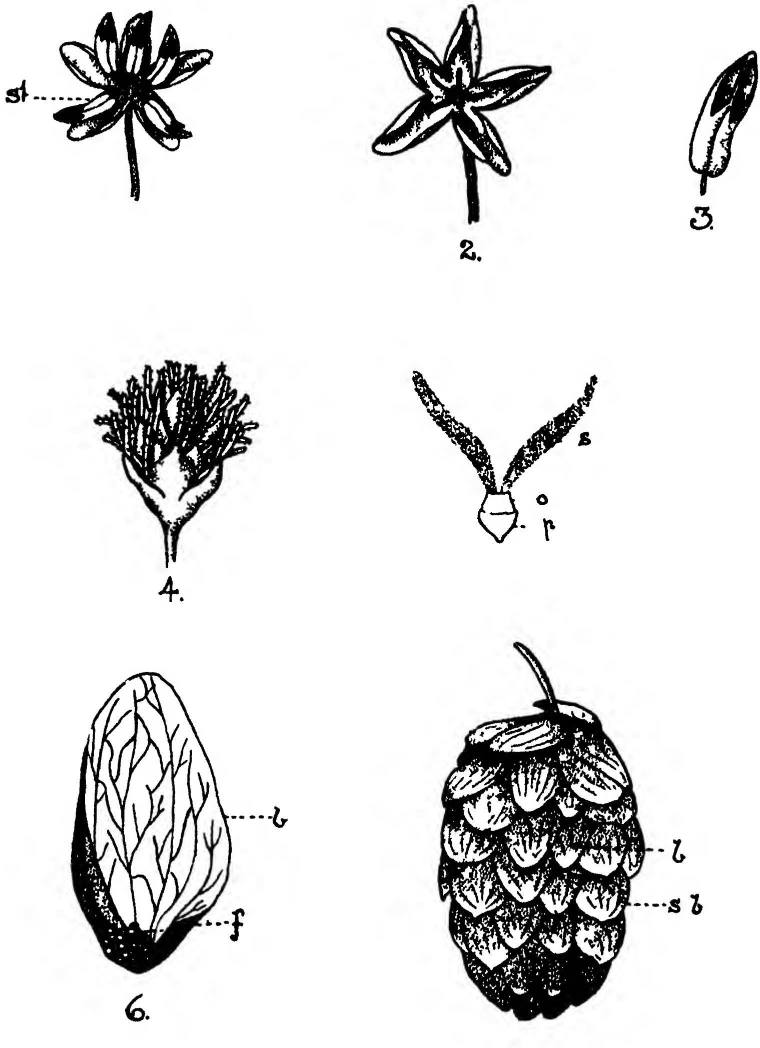

Fig. 1.

1.—A male hop flower. *s* perianth (sepal); *st* stamen.
2.—Perianth of male flower with anthers removed; the fine short filaments are visible.
3.—A stamen showing the dchiscence of the anther.
4.—A young female inflorescence (a hop "in burr") showing the stigmas ("brush").
5.—A complete female flower. *p* the cup-shaped perianth; *o* ovary; *s* stigma.
6.—A bracteole (*b*) surrounding the ripe fruit ("seed") *f*.
7.—A ripe hop showing the stipular bracts (*s b*) and bracteoles (*b*).
(1—6 × 8, 7 natural size.)

During the "growing out" period, which usually lasts about six weeks, it will be observed that there are two very distinct kinds of bracts in the strobile. At the four corners of the hop occur the seedless stipular bracts (7, Fig. 1), which are further distinguished by their greenish colour, the limited development of lupulin glands and their acuminate apex. On the flat sides, the rounded, bright yellow, seed-bearing bracteoles[1] (6, 7, Fig. 1) occur in pairs.

While carrying out various cross-fertilisation experiments during the past summer, it was noticed that the young hops which were not pollinated, and which served as check experiments or controls, always remained in burr for a much longer period (often more than a week) than those which were pollinated. On the other hand, it was found that when the young hops were artificially pollinated, the stigmas turned brown and withered in three or four days and then fell off. The dying away of the stigmas was at once followed by the growth in size of the young hops. In a word, the pollinated hops started to grow out at once, while those which had not received pollen did not develop immediately, but waited, as it were, for this process to take place. Thus as the pollinated hops began growth a week to ten days before the controls, it became a matter of great interest to follow the subsequent development of both.

It was found that the non-pollinated hops never recovered their lost ground. They turned out at picking time to be small, green and unripe, and compared very unfavourably with the well-grown, golden yellow and ripe pollinated hops. The difference between the two sets was so great in all respects that they would never have been taken for hops of one variety, much less for hops growing on the same bine and on opposite pairs of laterals. While the controls were very small and green, the pollinated hops only differed from the normal hops on the same bine in being rather more symmetrical and better developed specimens with the free ends well closed in.

The differences between the two sets of hops at picking time may be seen in Fig. 2, Plate II. The control hops are in the centre, the bunches on either side having been pollinated. Fig. 2 represents three bunches of Colegate's hops from the same bine, and developed from laterals of nearly equal strength. The control bunch in the centre is quite seedless, while the pollinated bunches on either side are well-seeded.

[1] The stipular bracts and bracteoles of the hop are spoken of as "petals" by the hop-growers.

A further point of some interest was noted when the experimental hops were picked. It was found that the controls, which in all cases turned out to be seedless, were attacked by mould (*Sphærotheca humuli*, [DC] Burr.) to a much greater extent than the seed-hops which had been pollinated. Indeed these latter were singularly free from this parasite. Fertilisation therefore seemed not only to stimulate the growth, to hasten ripening, and to improve the colour, but also to increase the mould-resisting power of the hop itself.

The behaviour of the experimental hops suggested the desirability of extended observations in hop gardens to determine, if possible, whether the above results, arrived at under somewhat artificial conditions, are borne out in actual practice.

In the first place, a very large number of nearly ripe hops were examined in order to determine to what extent seed-production takes place. *No well grown-out hops were seen without seeds.* Further, it was found possible to count the seeds in any hop by observing the size of the bracteoles. Where seeds have set, the bracteoles are much larger and brighter yellow than those which only bear rudimentary seeds. In Fig. 3, bracteoles with (A), and without (B) fully developed seeds are shown. In all cases those with mature seeds are larger than those with rudimentary seeds. The hops on the right and left (C) represent extremes of well grown-out seed hops. The two hops (E) are seedless hops from a control bunch, while (D) represents a hop from a pollinated bunch. The difference in size of the bracteoles with and without perfect seeds is well seen in the large hop on the left (C).

Since the stigmas at the stalk-end of the hop are ready for pollen first, after which those towards the free end become successively receptive, a considerable period elapses between the beginning and end of pollination in any particular hop. In view of the scarcity of males in many gardens at the present time it appeared probable therefore that hops would be found seedless at the base, fertile at the free end and *vice versâ*. A search showed that this was the case. In a garden which contained only three male hills in fourteen acres numerous hops were found seedless and small at the base, but fertile and enlarged at the free end. Others were found seedless and constricted in the centre only. Fig. 4 illustrates this point.

It was next noticed that fully developed seed hops and badly grown-out, unripe, seedless hops were often to be found on the same bine. In such cases, pollen was probably abundant when the earliest hops on

the bine were in burr, but was not available when the later hops were ready for pollination. Hence, in order to obtain all the hops on a bine in a well grown-out condition pollen must be available during the whole burr period.

Evidence on the subject of the special liability of seedless hops to mould attacks was now sought in the field. It will be remembered that in the cross-fertilisation experiments it was noticed that the seedless hops in the control bunches were attacked by mould to a much greater extent than the seed hops on the same bine. Accordingly, a large number of half seedless hops were examined to see whether the mould did more damage on the seedless part than on the seeded portion. This was found to be the case. The seedless portions were usually completely destroyed, while the fertile portions grew out almost normally (Fig. 5). Further, in hops which contained only one or two fertile bracteoles it was constantly seen that these structures were hardly affected, while the rest of the hop was destroyed (3–5, Fig. 5).

The above experiments and observations all point to the necessity of fertilisation in the production of well-grown hops of the desired colour. On the other hand, the absence of fertilisation leads to small, green, unripe hops, particularly liable to damage by mould. As is well known, it is during the burr stage that hops are liable to total destruction by mould. This seems, apart from climatic considerations, due to two main causes. In the first place, the feathery stigmas arrest the mould spores as they blow past, and also tend to keep the atmosphere around the spores moist and so assist in their germination. Secondly, unless pollination takes place as soon as the stigmas are receptive there seems to be a pause in development, during which the hop waits for the process to take place. It would appear, therefore, that any arrest of growth at this period is particularly dangerous, and everything should be done to carry the young hops rapidly through this critical phase.

It seems difficult, therefore, to escape the conclusion that, under the conditions obtaining in Kent, the growth of seed hops rather than seedless hops should be aimed at. Before, however, any special recommendations are made on such an important subject as this, it is proposed to carry out further investigations during the coming season on the lines indicated below. The present experiments are put forward merely as a contribution to the subject.

The advantages of growing seed hops seem to be the following:

1. Large, heavy, brightly coloured, and well grown-out specimens.
2. Early ripening.
3. Increased mould-resisting power.

The disadvantages, on the other hand, would appear to be:

1. The space taken up and the trouble involved in growing suitable males for the various gardens. It is obvious that unless the males shed their pollen when the hops are in burr they are useless as far as the particular garden in which they are growing is concerned. There seems to be quite as much variation in the time of ripening among male hops as there is among the females. Further, it appears that a good many of the males met with in hop gardens ripen too early and shed most of their pollen before the surrounding hops are in burr. Some trouble, therefore, would have to be taken to select and grow male hops which would correspond to the full burr period of the various varieties grown in the south-eastern districts of England. Probably suitable males could be raised from seeds.

2. The possible difference in brewing value between seed and seedless hops. The Germans say that 116 lbs. of seed hops are equal, in this respect, to 100 lbs. of seedless hops. Next season it is proposed to estimate the total resins present in equal weights of seedless and seed hops in several of the more important English varieties. With regard to this point, however, it might be mentioned that, in all the cases examined this year, it was found that the lupulin glands of the seedless hops were not so ripe at picking time as those in the seed hops on the same bine. This difference in ripeness therefore may lead to some difficulty in carrying out the proposed experiments.

3. The possibility of the more rapid exhaustion of the hills through the more frequent formation of perfect seeds. In order to throw light on this point an analysis of hop seeds (Early Bird Bramlings) has been made by Mr F. T. Holbrook. The results are given in the following table, together with the figures relating to the whole hop.

It will be seen that the seeds are richer in nitrogen and phosphoric acid. In view, however, of the liberal manner in which hops are manured, it is hardly likely that increased seed production will either exhaust the soil or weaken the plant.

The opinions of several leading Kentish hop-growers were now sought on this question of the value of male plants. The views ob-

Analyses showing the fertilising constituents contained in hops and seeds, stated in parts per 100 *of the materials as taken from the pocket.*

	Ash	Nitrogen	Potash (K_2O)	Phosphoric Acid (P_2O_5)	Lime (CaO)
Whole hops............ ..	6·33	3·22	2·45	1·18	1·06
Seeds.......	6 53	4·64	1·39	2·33	·46

tained differed widely. Many regard the males as useless and have them grubbed after picking time. Others, especially in East and Mid Kent, consider that a few males are useful and improve the general welfare of the gardens. Mr W. H. Hammond, of Canterbury, in a very interesting letter dated October 17th, 1904, sums up his experiences as follows:

"With regard to male hops in our gardens in East Kent, I have all my life understood from growers that they thought it an advantage to have a few male plants scattered about. My father, who was a large planter in the Petham Valley for sixty years or more, always grew a few males.

"The perfect seeds for one thing help to make weight, and our English brewers do not object to them, but apart from that many men seem, in the past, to have had an idea that it was better for the general welfare of the gardens if there were a few males present.

"I can recollect talking this matter over more than thirty years ago with the late Mr S. J. Saukey, of South Hill, Hastingleigh, when he instanced the case of a garden at Hastingleigh Court Lodge Farm, which had always been a good one and had always had a considerable number of male plants in it, but at one time a fresh tenant came who thought them useless, and destroyed them all; after that the garden moulded, went to the bad, and was soon grubbed.

"Personally, I have always thought it best to keep a few male plants in my own garden."

Mr H. O. Hubble, of Hunton, Maidstone, writes:

"I consider that the influence of the male hop in a hop plantation is decidedly a matter worthy of further experiments on your part, especially because the results you have already obtained seem conclusively to prove

what some growers in Mid Kent have for many years believed, as the result of observation only.

"I cannot pose as an 'experienced grower,' but I have often noticed that the female hops in close proximity to a 'seeder[1]' come into hop earlier, are larger and more mature, in fact are generally more 'complete,' if I may so put it, than those which are not so situated.

"The rule does not, of course, always hold good, but that, you have explained, is because the male hop has come to maturity either too early or too late for 'pollination' to take place.

"Your statement that a 'pollinated' hop is better able to resist mould is extremely interesting and valuable, and the fact that 'pollinated' hops always contain seeds is surely a weighty argument in favour of the preservation of the male plant.

"My uncle, a grower of long experience, has always insisted on the value of the male plants, and would always have some of them planted about each garden, and there are other large growers in this district who think and act in the same way."—(Letter, Nov. 4th, 1904.)

Turning now to the literature of the subject the greatest diversity of opinion is found. The German investigators seem to agree on this question, and regard male hops as useless or even harmful. It is even said that male plants are not allowed in Spält under a heavy penalty. The hops from this district, however, are not seedless, but contain seeds, so that the efforts made in striving after a seedless hop are not altogether successful.

The American growers, on the contrary, think that imperfect fertilisation is a frequent cause of light weight hops of inferior quality. A leading Oregon grower relates his experience as follows:

"This complaint of the Germans of seeds in American hops was first heard in 1882, when hops were so high, and caused some growers on this coast to grub out and destroy all their male vines. The result was that their hops did not mature well. They were large, green, light, feathery things, with neither colour nor strength, and dealers would not handle them. I have seen this experiment tried in Southern Oregon with the same result. I planted a yard myself once without being able to get male roots, and my hops were poor, lean things, until I obtained the male plants and got them to grow vigorously, when my hops became of good colour when ripe, with plenty of strength, and I heard no more complaints of poorly matured or lean hops. I am now fully

[1] In Kent, male hops are sometimes called "seeders."

convinced that hops, like many other plants, require fertilising from the bloom, and, as none but the male hop bears any pollen, it is necessary to have a sufficient number of these in a hop yard, so that the flowers of each vine may be fertilised. And brewers, if they expect a good, solid, bright-coloured, well-matured hop, well filled with lupulin, must expect also to see the hop well filled with good, large, purple seed. If they do not wish seed they cannot expect lupulin. Germany may produce good hops without seed, but it cannot be done here, at least such has been my observation and experience. Therefore my advice is to let the male hop alone, and if in a season of high prices a few brewers complain of extra weight in the seed, pay no attention, but go ahead[1]."

It must be remembered, however, that the conclusions of observers in Germany and the United States, although of great interest, are not necessarily applicable to the conditions which obtain in England. The varieties cultivated abroad are not the same as those grown in this country, the climatic conditions are widely different, and there does not seem to be the same danger from mould as in England.

The directions in which further work is desirable in this subject seem to be as follows:

1. The effect of pollination and its absence in gardens which are particularly liable to mould at the present time. It is well known that, other things being equal, mould is most prevalent where the air is still, and where the hops are "housed in." In such situations there is also the smallest chance of pollination, and it is possible that the lack of pollen may partly account for the damage done by mould.

2. The effect of pollination in gardens where the hops do not usually grow out well.

3. The influence of temperature and moisture on the liberation of pollen and the spread of mould. Generally speaking, damp, cold weather favours mould and also checks the liberation of pollen.

4. The possible relation between the percentage of seed and the total crop. Fertilisation seems to stimulate the growing out of the hop, and its absence has the reverse effect.

5. The comparison of the brewing value of seedless and seed hops. The determination of the total resins seems to be the best way of arriving at an opinion on this point.

6. Comparative infection experiments with mould on seed and seedless hops.

[1] *The Hop—its culture and cure*, H. Myrick.

7. The influence of pollen from different males on the development of particular varieties.

8. The effect of various washes on hops when in burr. Possibly fertilisation may be interfered with or even prevented when hops are sprayed at this stage.

9. The influence of seed formation on the "thickness" of the sample as taken from the pocket.

10. The effect of fertilisation on the compactness or "density" of the hop.

As far as possible these lines of enquiry will be followed up during the coming year.

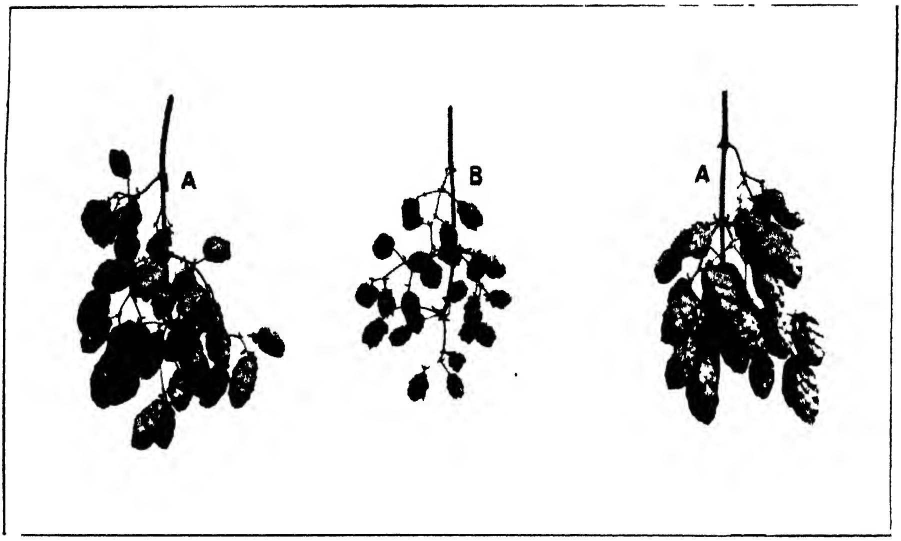

Fig. 2.—Seed and Seedless Colegate's Hops.

A. -Seed hops (pollinated). B.--Seedless hops (control not pollinated).
Photographed 42 days after pollination.

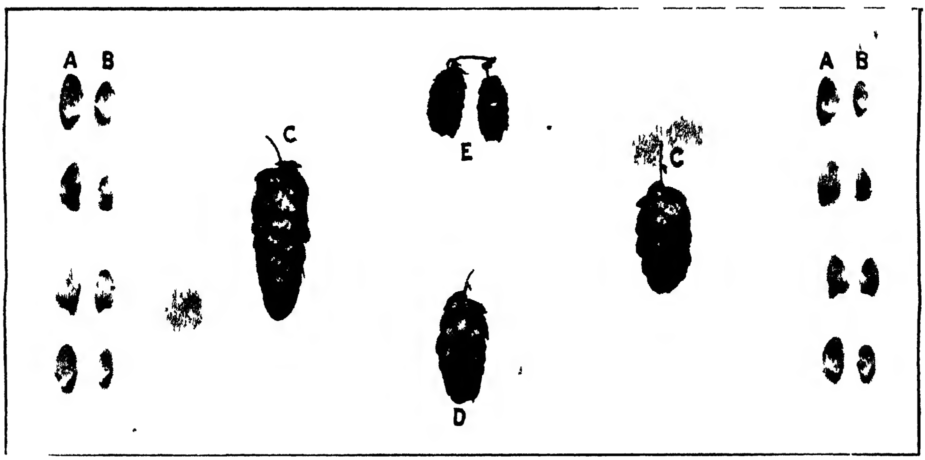

Fig. 3.—Seed and Seedless Hops and Bracteoles.

A.—Bracteoles with perfect seeds. C.--Seed hops (naturally pollinated).
B.—Bracteoles with rudimentary seeds. D.—Seed hops (artificially pollinated).
E. Seedless hops (control—not pollinated).

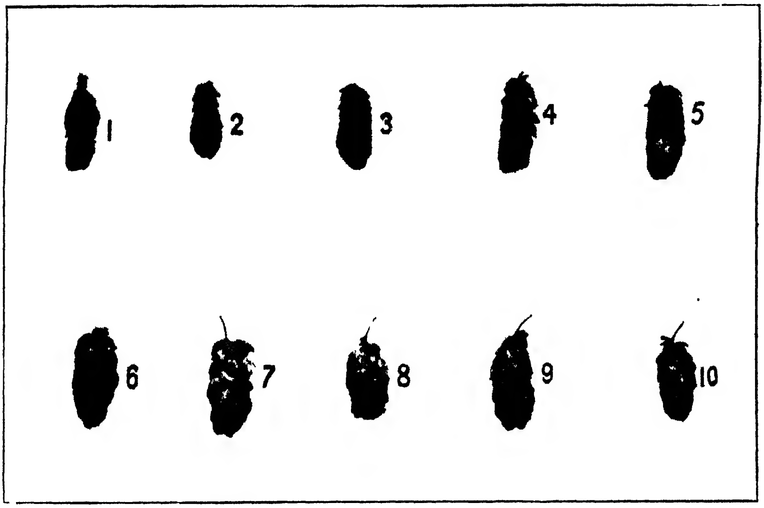

Fig. 4.—Partially Seedless and Seed Hops.

1. -Seedless in the middle only. 2–5.—Seedless at the stalk end only.

6–10. -Uniformly seeded and normally developed hops.

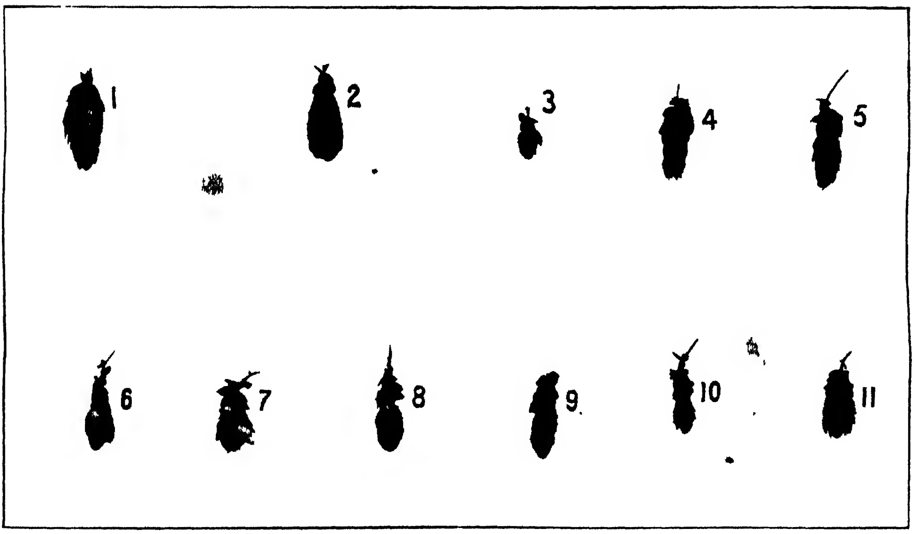

Fig. 5.—Hops attacked by Mould in the Seedless Portion.

1.—Attacked at the free end. 2.—Attacked at the stalk end.

3–5. Fully developed fertile bracteoles in mouldy hops. 6–11.—Attacked in the seedless portion.

THE IMPORTANCE OF THE REMOVAL OF THE PRODUCTS OF GROWTH IN THE ASSIMILATION OF NITROGEN BY THE ORGANISMS OF THE ROOT NODULES OF LEGUMINOUS PLANTS

A PRELIMINARY NOTE,

By JOHN GOLDING, F.I.C., F.C.S.,

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FOR nearly eighteen years the problem of the fixation of nitrogen by the root nodules of leguminous plants has been the subject of investigation by numbers of workers in many parts of the world, and steady progress has been made towards realising the conditions under which the organism works in the nodule. Artificial nutrient media have been prepared closely resembling the food supplied by the plant, and the organism itself has in recent years been induced to grow in artificial culture in the characteristic "bacteroid" forms approximating to those which are found in nature.

The actual process of fixation as it occurs in the nodule is, however, still wrapped in mystery, and experimenters have been well-nigh baffled in their attempts to produce it under artificial conditions; the results obtained being valuable mainly as affording proof that the plant itself is a leading factor in the process of assimilation, and plays a more important *rôle* than that of merely furnishing the organism with suitable food.

My own work on the subject, which has extended over some eight or nine years, has served to confirm the view that the plant was a more active agent than had previously been supposed, and that the solution of the difficulty lay in the direction of getting as closely as possible, not only to the natural conditions of food, but also to the natural conditions of the growth in the nodule.

With this idea I planned a series of new experiments, of which the main feature was the removal of the soluble products of growth

on lines similar to those which obtain in nature. This removal was effected by the use of a porous Chamberland filter-candle which was fixed in the culture vessel. Fairly aërobic conditions were also preserved by passing purified air through the cultures.

In the first experiments the parts of the plants taken were not subjected to any heat which might destroy the natural enzymes occurring in the nodules, though in later experiments assimilation was obtained in the sterilized extract from the parts of the plants, indicating that the plant enzymes did not play an important part in the assimilation obtained. In these first experiments in which the parts of the plants were simply cut up and well bruised in a mortar, the initial infection was provided by the organisms present in the crushed nodules. In later experiments with sterile liquids the cultures were inoculated from an agar slant of the pure organism from the nodules of the kind of plant under experiment, the organisms being scraped off with a sterile platinum needle and suspended in the liquid.

Apparatus.

The apparatus used for these experiments consisted of three parts:—

(1) A porous filter-candle fixed in an inverted bell-jar and covered with another shorter bell-jar of the same diameter, in the neck of which was a rubber cork with three holes admitting two tubes bent at right angles, and a straight tube. This piece of apparatus could be sterilized by heat, and when removed from the steam sterilizer, the ground-glass rims of the bell-jars could be made quite air-tight by painting with sterile paraffin wax. All other openings were plugged with glass stoppers or cotton-wool.

(2) A filter flask fitted with, (*a*) a long tube filled with cotton-wool, which tube was attached to the receiver of an air-pump; and (*b*) a rubber cork with one hole, through which passed a glass tube which was joined to the nozzle of the filter (1).

(3) An apparatus for purifying the air, consisting of two wash bottles and a long tube plugged with cotton-wool. The first of these wash bottles contained sulphuric acid and ferrous sulphate, the second wash bottle contained 50 c.c. of 10th normal sulphuric acid which was always found to require for neutralisation 50 c.c. 10th normal potash at the close of the experiment.

The apparatus (3) was joined to one of the bent tubes passing through the top of the bell-jar, the other bent tube being attached to an aspirator.

EXPERIMENT 1.

In the first experiment the material used consisted of, (*a*) the leaves and stem, (*b*) the roots and nodules of young bean plants, these parts were cut up fine, well bruised and sampled in a mortar.

The well-sampled materials were quickly weighed out, 500 grams of stems and leaves, and 20·02 grams of roots and nodules being taken for the experiment.

Portions were also weighed out into Kjeldahl flasks for duplicate determinations of the nitrogen in both parts.

Ammonia-free distilled water was then added to the crushed parts in the bell-jar (1). The air-pump and aspirator were set to work, and the apparatus left at the temperature of the room, which fell as low as 9° C.

On the third day an analysis of the air which had been aspirated through the crushed plants and water in the bell-jar, showed 8·6 per cent. carbon dioxide, and 8 per cent. oxygen. Oxygen gas was therefore substituted for air and passed through the apparatus for about an hour to encourage a more aërobic growth.

The receiver had to be changed from time to time as it filled. The filtrates were carefully measured and duplicate determinations of Nitrogen made in each lot by Kjeldahl's method, 100 c.c. being taken for each determination.

At the end of 15 days the solid residue was taken out, and when all the liquid had drained off, the wet residue and scrapings from the candle were well sampled, and the nitrogen determined in duplicate. No account was taken of the nitrogenous matter which might be left in and on the porous filter, it being thought that with so large a bulk of material this might be safely neglected if any considerable assimilation had taken place.

The results of this experiment are shown in the following table:—

	Nitrogen in grams.
500 grams of Stems and Leaves	2·865
20·2 grams of Roots and Nodules (quite fresh)	0·094
3000 c.c. Ammonia-free Distilled Water	0·000
Total Nitrogen to start with	2·959
2870 c.c. Filtrates and Drainings	0·731
566·2 grams of Wet Residue	2·570
Total Nitrogen after experiment	3·301
Total gain of Nitrogen during experiment	0·342

Experiment 2.

In this experiment the fresh unheated cold water extract from young pea plants was taken in a similar but smaller apparatus.

Five grams of pure dextrose were added in this case, but the solid matter of the plant was not used.

The results obtained were as follows:—

	Nitrogen in grams.
500 c.c. of Liquid Extract containing 5 grams of Dextrose	0·329
At the end of the experiment:	
400 c.c. of Filtrate contained	0·2632
72 c.c. of unfiltered Residue...........................	0·0902
	0·3534
Total gain of Nitrogen during experiment	0·0244

Experiment 3. *Blank Experiment.*

In this experiment the apparatus was used as in Experiments 1 and 4. 1500 c.c. of nutrient medium as used in Experiment 4, was placed in the bell-jar containing the Pasteur filter, the nozzle of which was closed with a piece of rubber tubing plugged with a sterile glass rod.

The whole of this part of the apparatus was then sterilized in the steam sterilizer at 100° C., the rims of the bell-jars being sealed with paraffin wax while still hot. The other parts of the apparatus were now joined up and the filtration allowed to proceed slowly as in the case of the other experiments.

At the close of this blank experiment, the following result was obtained:

	Nitrogen in grams.
1500 c.c. Sterile Nutrient Medium to start with...	0·2422
Filtrate and Residue after experiment	0·2418
Loss of Nitrogen in blank experiment ...	0·0004

Experiment 4.

The object of this experiment was to find out if the assimilation of free nitrogen could be made to take place under the conditions of experiment when a ***sterilized nutrient medium*** and ***a pure culture*** were used.

The apparatus used was exactly the same as in Experiment 3, the medium to be used was well sterilized in the bell-jar.

A measured quantity of the suspended scrapings from a pure agar slant was added when the liquid had sufficiently cooled.

The nutrient medium was made up as follows:—

To 1 litre of sterile Pea extract was added, 3·3 grams of Dextrose; 6·67 grams of Cane Sugar; 1·0 gram of Dipotassium Phosphate; 0·5 gram of Magnesium Sulphate; 0·1 gram Succinic Acid; 0·03 gram Sodium Chloride; 0·03 gram Ferrous Sulphate; 0·03 gram Manganese Sulphate.

The experiment lasted 13 days. The results obtained were as follows:—

	Nitrogen in grams.
1500 c.c. Nutrient Medium contain	0·2422
50 c.c. pure Culture	0·0096
Nitrogen to start with	0·2518
800 c.c. of Filtrate contain	0·1434
730 c.c. " "	0·1042
Insoluble matter washed from filter	0·0357
Nitrogen at the end of the experiment	0·2833
Total gain of Nitrogen	0·0315

EXPERIMENT 5.

This experiment was the same as Experiment 4, except that a much smaller apparatus was used and the experiment was continued for 22 days.

Result.

	Nitrogen in grams.
50 c.c. of pure Culture in water	0·0093
200 c.c. Nutrient Liquid	0·0924
Total Nitrogen to start with............	0·1017
On filter	0 0326
244 c.c. filtrate	0·0761
Nitrogen at end of experiment	0·1087
Total gain of Nitrogen	0·007

Attempts were made to grow the organisms on agar cultures spread on porous drying plates, which were floated on dishes containing dilute sugar solutions and covered with glass lids, purified air being passed over the surface.

Agar cultures were also made in sterile parchment dialysers floated on sugar solutions; and also in porous pots surrounded by sugar solutions. The results in all these cases were unsatisfactory.

Other experiments were tried in which the sterile liquids used above were placed in large flat-bottomed flasks arranged in series and inoculated with pure cultures. Purified air was passed over these cultures but in no case did any appreciable assimilation of nitrogen take place, the loss or gain of nitrogen did not exceed the limits of experimental error.

In some of these experiments large quantities of sugar solution were fed to the culture day by day, from sterile separating funnels; but though conditions obtaining in the plant were thus imitated in another respect, the results were not nearly so satisfactory as the cases in which the removal of soluble products was accomplished by means of porous filters.

Further experiments are now being conducted on the subject, a Novy's filtering apparatus being used instead of the apparatus (1), pressure is also being used instead of suction to make the liquid pass through the filter, thus getting nearer again to the natural conditions.

Conclusion.

The results of these experiments, in which larger amounts of nitrogen have been assimilated in artificial cultures than in any previous experiments, indicate that the conditions of growth obtaining in culture vessels fitted with a porous filter through which the soluble products of growth of the organism are being slowly removed, favour the assimilation of nitrogen.

It thus seems probable that one of the functions of the host plant is the removal of soluble products of growth, which when present in previous artificial cultures have prevented the assimilation of nitrogen.

THE ANALYSIS OF THE SOIL BY MEANS OF THE PLANT.

By A. D. HALL, M.A.,

Director of the Rothamsted Experimental Station (Lawes Agricultural Trust).

One of the main problems placed before the agricultural chemist is the estimation of the requirements of a given soil for specific manures, or the interpretation, by means of data obtained in the laboratory, of the behaviour of the soil towards these manures, as seen in properly arranged field experiments. For various reasons the obvious method of determining the proportions of Nitrogen, Phosphoric Acid, and Potash in the soil fails in many cases to give the required information; even the more modern methods of measuring only the quantities of these materials which are attacked by weak acid solvents, and in consequence regarded as available to the plant, by no means always accord with the results of experience. Hence from time to time attempts have been made to attack the problem from another side and to use the living plant as an analytical agent. The scheme is to take a particular plant grown upon the soil in question, and determine in its ash the proportions of constituents like phosphoric acid and potash. Any deviations from the normal in these proportions may then be taken as indicating deficiency or excess of the same constituent in the soil and therefore the need or otherwise of specific manuring in that direction. The theory rests on two assumptions, first that each plant has a typical ash composition, constant when the plant is grown under similar conditions; secondly that the variations in the proportion of such a constituent as phosphoric acid will reflect the amount of that plant food available in the soil, as measured by the response of the crop to phosphatic manuring. From this point of view a number of investigations have already been made: Hellriegel[1] discussed the relative

[1] *Landw. Vers. Stat.* II. 1869, p 136.

variations of the proportion of potash in the ash of barley straw and of the soil in which it was grown, Heinrich[1] analysed the roots of oats and fixed certain minima, below which the need for specific manuring was indicated.

Atterberg[2] used the oat plant in his researches and established a series of minima for both the whole plant and the grain, from which the soil conditions could be deduced

Godlewski[3] analysed the ash of crops of wheat, potatoes, and barley grown on experimental plots on a particular soil, so as to compare the variation in yield induced by specific manures with the variation in the composition of the ash.

The following experiments were undertaken with a view of testing the general applicability of the method and of measuring its agreement with the usual processes of soil analysis.

I. The Composition of the Ash of Oats grown in various Soils.

The first experiments were made with oats in pots in 1902. Six soils were selected representing widely varying types, of whose reaction to fertilisers in the field something was already known, and two glazed pots holding about 20 kilos. were filled with each soil. Black Tartarian oats were sown in all and finally reduced to 8 plants in each pot, these were harvested in July when the corn was partly formed but before it was ripe. The whole of the growth above-ground was cut away, dried, burnt, and the potash and phosphoric acid determined in the ash. Analyses were made of the soil used for each pot; "total" phosphoric acid and potash were determined in the solution obtained by digesting the soil with concentrated hydrochloric acid in a loosely stoppered flask on the water-bath for two days, the "available" constituents were estimated by Dyer's method of digesting with a one per cent. solution of citric acid[4].

The following tables show, I. The amount of dry matter and ash produced in each pot, II. The composition of the ash and of the soils as regards potash and phosphoric acid.

[1] *Grundlagen z. Beurtheilung der Ackerkrume*, 1882. [See also Dickow, *Jour. Landw.* xxxix. 1891, p. 134, and Helmkampf, *ibid.* xl. 1892, p. 168]

[2] *Landw. Jahr.* xv. 1886, p. 415; xvi. 1887, p. 757; *Jour Landw.* xlix. 1901, p. 97.

[3] *Zeitsch Land. Vers. Wesen in Oesterreich*, iv. 1901, p. 479.

[4] *Trans. Chem. Soc.* 1894, p. 115.

TABLE I.

Dry Matter and Ash of Oats in Pots, 1902.

	Dry Matter grammes	Ash grammes	Ash °/o in Dry
Folkestone Sand ...A	19·1	2·5385	13·29
" " ...B	19·0	2·1150	11·13
Chalk ....A	17·9	2·0212	11·29
" ....B	15·2	1·5716	10·34
Brick Earth ....A	23·7	2·2544	9·51
" " ....B	22·6	2·1350	9·45
Gault ....A	17·36	1·2851	7·40
" ....B	17·55	1·0634	6·06
Weald Clay ....A	17·45	1·3648	7·82
" " ....B	17·32	1·3538	7·82
Tunbridge Wells ...A	25·3	2·0551	8·12
" " ...B	23·8	2·4762	10·40

TABLE II.

Oats grown in Pots.

Season, 1902.

	In Ash °/o			In Soil °/o	
	A	B	Mean of A & B	Total	Citric acid soluble
PHOSPHORIC ACID					
Folkestone Sand ...	9·15	12·63	10·89	0·354	0·142
Brick Earth	7·19	7·74	7·46	0·162	0·0401
Gault Clay	5·92	6·29	6·10	0·182	0·0144
Chalk	5·26	5·36	5·41	0·14	0·0115
T. Wells Sand	5·02	4·58	4·80	0·1117	0·021
Weald Clay...........	3·51	4·31	3·91	0·063	0·0023
POTASH					
Weald Clay	33·4	32·0	32·7	0·528	0·024
Folkestone Sand ...	19·5	26·2	22·85	0·648	0·035
Brick Earth	20·01	20·1	20·05	0·468	0·016
Gault Clay...........	16·4	21·7	19·05	0·614	0·018
T. Wells Sand	16·5	19·6	18·05	0·144	0·028
Chalk	11·6	12·74	12·17	0·181	0·0125

Considering first the phosphoric acid results, it will be seen that the order in which they stand according to the proportion of phosphoric acid in the ash is substantially the same as the order indicated by the citric acid soluble phosphoric acid in the soil. The Folkestone Sand which stands at the top is clearly abnormal; the sample of soil was taken from a poor arable field on this notoriously poverty-stricken formation, much of which in the immediate neighbourhood consists of barren sandy heaths, but evidently it must have been drawn where a dung heap had recently stood, or something equivalent had occurred, so high are the proportions of phosphoric acid and potash. The exceptional proportion of citric acid soluble phosphoric acid is reflected in the very high proportion of this constituent also present in the ash. At the other end of the scale stands the Weald Clay soil with the low proportion of 3·91 per cent. phosphoric acid in the ash, and with the exceptionally low figure of 0·0023 per cent. of citric acid soluble phosphoric acid in the soil. The other figures are intermediate, although the Tunbridge Wells Sand with one of the smallest proportions of phosphoric acid in the ash shows a fairly high proportion, 0·021 per cent., of citric acid soluble phosphoric acid in the soil.

The field experiments on the various soils (putting aside the Folkestone Sand) indicate that only the Weald Clay is in specific need of phosphatic manuring. The Tunbridge Wells Sand, on which the oats contained but little more phosphoric acid than did those grown on the Weald Clay, has repeatedly shown in field trials no response to phosphates, standing in every respect in the greatest possible contrast to the Weald Clay. Looking at the results as a whole the determinations of citric acid soluble phosphoric acid indicate the characteristics of each soil towards phosphatic manuring much better than do analyses of the ash, the casual variation between the phosphoric acid in the ash of the two pots *A* and *B* on the Weald Clay being actually greater than the mean difference between the Weald Clay which needs phosphatic manuring and the Tunbridge Wells Sand which does not. The potash results are even more inconclusive; the ash analysis brings the Weald Clay to the top, and certainly this soil can supply all crops amply with potash. The ash analysis also brings the Chalk to the bottom, which again agrees with the result of field trials. But the oats on the Tunbridge Wells Sand contain little below the average amount of potash, whereas field trials had shown that the field from which this sample was drawn responded to potash manuring in a quite exceptional manner, a result again which is not indicated by the amount of citric

acid soluble potash in the soil. In these results also the casual variations from pot to pot are often greater than those induced by differences of soil.

The experiments above described were begun by Mr Guy L. Pilgrim, B.Sc., now of the Geological Survey of India; he prepared the pots and grew the oats until they were well advanced, he also prepared the soil for analysis and made some determinations before his departure for India.

II. COMPOSITION OF THE ASH OF CEREALS GROWN AT ROTHAMSTED.

In view of the unsatisfactory results thus obtained, the numerous ash analyses of the Rothamsted experimental crops were consulted to ascertain if they threw any further light on the question.

The amount of variation due to season and individuality must be ascertained before we can fix a standard from which to measure the deviations on the part of material grown on an unknown soil. The following table (III.) shows a comparison of the composition of the ash of the wheat crop, grain and straw, grown on certain of the permanent wheat plots at Rothamsted in two sharply contrasting seasons, 1852 being cold and a year of low yields, whereas 1863 was perhaps the most favourable season on record for the growth of wheat. It should be noted that previous to 1852 the manuring had not been exactly repeated year by year for Plots 7 and 11, but by 1863 the manuring had been repeated at least twelve times on these as on the other plots, so that the growth had then thoroughly settled down to the influence of the particular manuring adopted.

A consideration of these figures will show that the composition of the grain is but little affected by the manuring, the extreme variations in 1863 being from 31·54 per cent. to 34·42 per cent. of potash, and from 46·02 per cent. to 52·04 per cent. of phosphoric acid, variations of about nine and thirteen per cent. of the respective amounts. The seasonal variations between 1852 and 1863 amount to 9 per cent. for the unmanured plot and nearly 16 per cent. for the dunged plot as regards potash, and to 5·1 per cent. for the dunged plot as regards phosphoric acid. In other words, the seasonal variations in the composition of the ash of the grain are of the same order of magnitude as the variations induced by manuring. With the straw the variations in composition of the ash are more marked, but here again the variations due to season are almost as pronounced as those caused by extreme differences of manuring.

TABLE III.

Composition of Wheat Grain and Straw as affected by manuring and season (1852 and 1863).

Broadbalk Field, Rothamsted.

Plot		2	3	7	10	11
Manuring*		Farm-yard Manure	Un-manured	N P_2O_5 K_2O	N only	N P_2O_5
Weight per bushel, lb.	1852	58·2	56·6	56·0	55·9	55·6
	1863	63·1	62·7	62·6	62·6	62·5
Weight of 100 grains, grms.	1852	3·46	2·88	3·08	3·26	2·94
	1863	5·35	5·02	4·79	4·51	4·76
Grain to 100 Straw	1852	49·6	53·9	41·0	47·3	47·8
	1863	67·5	70·4	59·4	74·3	70·4
GRAIN						
Ash in Dry Matter %	1852	1·98	2·03	1·95	1·83	1·96
	1863	1·85	1·95	1 73	1·56	1·72
Nitrogen in Dry Matter %	1852	2·02	2·08	2·29	2·48	1·95
	1863	1·52	1·65	1·53	1·70	1·79
Potash % in Ash	1852	27·22	29·66	28·64	28·10	27·19
	1863	31·54	32·32	33·64	34·42	32·58
Lime % in Ash	1852	2·79	2·87	3 04	3·51	3·80
	1863	2·34	2·66	2·73	3·85	3·89
Phosphoric acid % in Ash	1852	54·69	51·79	52·48	52·92	53·18
	1863	52·04	51·58	49·90	46·02	49·74
STRAW						
Ash in Dry Matter %	1852	7 04	7·04	5·55	5·60	6·10
	1863	6·42	7·12	5·22	5·40	5·48
Nitrogen in Dry Matter %	1852	0·46	0·57	0·87	0·89	0·46
	1863	0·25	0·33	0·36	0·35	0·44
Potash % in Ash	1852	12·86	10·54	15·12	10·53	5·12
	1863	17·97	13 02	24·96	14·25	9 81
Lime % in Ash	1852	3·87	2·52	5·26	5 60	5·78
	1863	3·78	4·39	5·55	6·92	7·39
Phosphoric acid % in Ash	1852	3 21	3·56	3·73	2·50	3·21
	1863	3·16	3·16	2·78	1·73	2 81

1852.—Winter favourable, Spring dry and cold, Summer rainy and cold. Crop generally below average.

1863.—Winter very open, Spring mild and open, May and June rainy, July and August moderate to high temperatures. One of the best wheat years on record both for quality and quantity.

* For details of the manuring see *Memoranda of the results of field experiments at Rothamsted.* Lawes Agricultural Trust, 1901.

TABLE IV.

BROADBALK WHEAT.

Percentage Composition of the Grain ash, and Straw ash.
Mixed Sample representing 10 years, 1882–91.

	Plot 2	Plot 3	Plot 5 *b*	Plot 7 *b*	Plot 10	Plot 11 *b*	Plot 12 *b*	Plot 13 *b*	Plot 14 *b*
GRAIN									
Ash (Crude) in Dry Matter %	1·96	1·94	1·99	1·91	1·67	1·86	1·83	1·87	1·86
Iron peroxide &c.	0·65	0·81	0·69	0·66	0·85	0·70	0·63	0·68	0·59
Lime	2·46	3·06	2·67	2·85	4·32	4·13	3·57	2·90	3·49
Magnesia	10·94	9·96	10·34	10·32	10·10	10·11	10·00	10·17	10·59
Potash	30·70	33·12	32·56	31·90	34·58	32·35	32·14	32·86	32·59
Soda	0·08	0·15	0·09	0·11	0·26	0·20	0·11	0·12	0·13
Phosphoric acid	51·57	48·23	49·91	50·09	41·32	49·28	49·19	49·86	49·33
Sulphuric acid	0·77	1·86	1·18	1·20	2·96	1·39	1·84	1·15	1·27
Chlorine	0·03	0·25	0·12	0·15	0·91	0·02	0·11	0·07	0·10
Silica	0·81	0·75	0·71	0·61	0·79	0·57	0·55	0·52	0·55
Sand	0·43	0·81	0·75	0·49	0·83	0·73	0·38	0·54	0·38
Charcoal	1·57	1·06	1·01	1·65	0·29	0·53	1·51	1·15	1·00
Total	100·01	100·06	100·03	100·03	100·21	100·01	100·03	100·02	100·02
Deduct O=Cl	0·01	0·06	0·03	0·03	0·21	0·01	0·03	0·02	0·02
Total	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00
STRAW									
Ash (Crude) in Dry Matter %	8·13	7·69	7·95	5·89	6·03	5·84	5·69	5·93	5·52
Iron peroxide &c.	0·31	0·94	0·60	0·50	0·59	0·43	0·33	0·34	0·41
Lime	3·66	4·37	3·50	5·69	8·21	9·14	7·73	5·39	7·70
Magnesia	1·52	1·51	1·41	1·76	2·24	2·25	1·92	1·53	2·46
Potash	18·49	13·50	16·34	25·89	13·56	9·91	14·68	23·28	14·87
Soda	0·09	0·10	0·09	0·21	0·40	0·58	0·57	0·03	0·33
Phosphoric acid	3·89	2·97	4·25	3·82	2·12	4·26	3·65	3·39	3·87
Sulphuric acid	3·45	3·80	4·77	5·41	6·78	5·44	5·33	5·07	5·31
Chlorine	2·93	1·81	1·90	6·60	2·58	1·66	2·89	5·61	2·81
Carbonic acid	—	—	—	—	1·19	Trace	None	None	Trace
Silica	64·91	67·63	65·29	49·68	60·73	65·19	61·93	54·26	61·06
Sand	1·13	3·26	2·21	1·32	1·78	1·46	1·43	1·76	1·39
Charcoal	0·28	0·52	0·07	0·61	0·40	0·06	0·19	0·60	0·42
Total	100·66	100·41	100·43	101·49	100·58	100·38	100·65	101·26	100·63
Deduct O=Cl	0·66	0·41	0·43	1·49	0·58	0·38	0·65	1·26	0·63
Total	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00

For an abbreviated description of the manures see Table V.

To ascertain more fully the effects of the manuring upon the ash composition and to compare it with the analysis of the soil it will be convenient to take a later series of analyses of the Rothamsted wheat set out in Table IV, which shows the composition of the ash both of grain and of straw of mixed samples representing the crops grown in the decade 1882–91, *i.e.* after the manurial treatment had been continued 30 to 40 years without change. In the first place it will be seen that the figures bear out the conclusion already stated that the ash of the grain varies very little in composition; the highest percentage of potash is 34·58 and the lowest 30·70, while the phosphoric acid varies between 44·32 and 51·57 per cent. of the ash. In the straw the variations are much greater, between 9·91 and 25·89 per cent. of potash, and between 2·12 and 4·26 per cent of phosphoric acid.

In the following table (V.) the phosphoric acid and potash figures given above are recalculated for the ash of the whole plant and compared with the analyses of soil from the same plots in 1893, as made by Dr B. Dyer[1].

The phosphoric acid shows but small variations, the only sample noticeably low is that derived from Plot 10, where continuous cropping with ammonium salts and without any phosphoric acid has seriously depleted the soil of this latter constituent. The soil analyses show that the unmanured Plot 3 is equally short of phosphoric acid, but as in this case there is an equivalent starvation in nitrogen and potash, the effect produced is a reduction of yield unaccompanied by any special variation in composition.

Turning to the potash plots, it will be seen that the variations are rather greater and are in accord both with the known manurial treatment of the plots and with the determinations of citric acid soluble potash. The wheat from the four plots 7, 13, 2, and 5 which receive potash annually, gives ash containing on the average 23·13 per cent. of potash; from the other five plots receiving no potash the proportion is only 16·93 per cent. If however we were using the analyses to indicate the need or otherwise of the soil for potash manuring, while the ash analyses show only a drop from 23 per cent. on the potash manured plots to 17 per cent. on the non-potash manured plots, on the same plots the citric acid soluble potash in the soil changes from 0·0278 per cent. to 0·0033 per cent., a step much more in accord with the known history of the plots.

[1] *Phil. Trans.* Vol. 194, pp. 235–290.

TABLE V.

BROADBALK WHEAT (1882–91).

Plot	Manuring*	In ash of whole plant %	In Soil (1893) % Total	In Soil (1893) % Citric acid soluble
	PHOSPHORIC ACID			
14	Nitrogen, Phosphoric acid	11·97	·204	·0442
5	Phosphoric acid, Potash	11·89	·219	·0642
11	Nitrogen, Phosphoric acid	11·82	·197	·0405
7	Nitrogen, Phosphoric acid, Potash	11·41	·195	·0547
12	Nitrogen, Phosphoric acid	11·40	·201	·0413
3	Unmanured	10·99	·114	·0078
13	Nitrogen, Phosphoric acid, Potash ..	10·93	·205	·0434
2	Farmyard Manure	10·23	·215	·0560
10	Nitrogen only	9·06	·1245	·0074
	POTASH†			
7	Nitrogen, Phosphoric acid, Potash ...	27·38	·262	·0232
13	Nitrogen, Phosphoric acid, Potash ..	25·36	·278	·0188
2	Farmyard Manure	20·38	·285	·0384
5	Phosphoric acid, Potash	19·39	·279	·0308
14	Nitrogen, Phosphoric acid	18·26	·240	·0024
12	Nitrogen, Phosphoric acid	17·88	·223	·0040
3	Unmanured	17·42	·220	·0032
10	Nitrogen only	17·27	·237	·0036
11	Nitrogen, Phosphoric acid . . .	13·89	·197	·0032

* For a full description of the manurial treatment of each plot see *Memoranda, &c., loc. cit.*

† Dr Dyer's determinations of total Phosphoric Acid and Potash were made in a solution obtained by evaporating the soil to dryness with strong Hydrochloric Acid and digesting afresh for one hour with more acid; the 48 hours' digestion previously described extracts about twice as much Potash from the same soils.

Table VI shows analyses of mixed samples of the ash of barley grain and straw from four plots for the ten year period 1882–91. As with the wheat the fluctuations in composition are in the main confined to the straw, the grain being comparatively constant in composition whatever the manuring. Table VII gives a comparison of the phosphoric acid and potash recalculated for the ash of the whole plant with

TABLE VI.

Hoosfield Barley.

Percentage Composition of Ash of Grain and of Straw.

Mixed Sample representing 10 years, 1882–91.

	Plot 1 A	Plot 2 A	Plot 4 A	Plot 1 AA
GRAIN				
Ash (Crude) in Dry Matter °/ₒ	2·10	2·34	2·44	2·15
Peroxide of Iron	0·95	0·70	0·88	0·83
Lime	4·00	3·71	3·02	3·38
Magnesia	8·19	8·01	8·32	8·34
Potash	27·20	24·99	28·25	26·95
Soda	2·70	2·90	0·44	3·26
Phosphoric acid	33·17	37·71	38·98	34·16
Sulphuric acid	3·03	2·13	2·00	2·97
Chlorine	1·98	0·43	0·21	1·31
Silica	17·65	18·10	16·49	17·87
Sand	1·17	0·89	0·79	0·87
Charcoal	0·41	0·53	0·67	0·35
Total	100·45	100·10	100·05	100·29
Deduct O = Cl	0 45	0·10	0·05	0·29
Total	100·00	100·00	100·00	100·00
STRAW				
Ash (Crude) in Dry Matter °/ₒ	4·65	4·71	5·26	4·68
Peroxide of Iron	0·68	0·63	0·61	0·59
Lime	11·72	14·67	9·67	11·20
Magnesia	2·18	2·40	1·63	1·86
Potash	12·72	7·17	28·99	12·63
Soda	10·22	11·54	1·81	14·00
Phosphoric acid	2·37	3·66	3·22	2·23
Sulphuric acid	5·85	5·57	5·92	6·26
Chlorine	8·78	7·03	9·06	4·15
Carbonic acid	1·36	1·41	2·48	2·74
Silica	48·25	44·89	36·24	42·91
Sand	2·70	2·46	2·12	2·15
Charcoal	0·15	0·15	0·34	0·21
Total	101·98	101·58	102·04	100·98
Deduct O = Cl	1·98	1·58	2·04	0·98
Total	100·00	100·00	100·00	100·00

TABLE VII.

HOOSFIELD BARLEY (1882–91).

Plot		Phosphoric acid			Potash		
		In pure ash of whole plant °/o	In Soil (1889) °/o		In pure ash of whole plant °/o	In Soil (1889) °/o	
			Total	Citric acid soluble		Total	Citric acid soluble
1 A	Amm.-salts only	11·75	·097	·0060	17·43	·267	·0020
2 A	„ + Phosphate	14·84	·173	·0425	13·14	·248	·0023
4 A	„ + Phosphate and Potash	13·97	·182	·0500	29·41	·326	·0298
1 AA	Sodium Nitrate only	11·66	·104	·0067	17·11	·136	·0050

the total and citric acid soluble constituents in the soil. The soil analyses were made by Dr B. Dyer[1] on samples drawn in 1889.

Inspection of these results shows that the variations in the proportions of phosphoric acid in the ash are too small to be of value in interpreting the condition of the soil towards phosphoric acid manuring, the information afforded by the weak citric acid being far more decisive. As regards potash the variations are very strongly marked, the barley plant from the one plot which had received potash containing about twice as much potash in the ash as did the three other samples from plots unmanured with potash.

These results are fully confirmed by a later series of analyses of the ash of the grain and straw grown on four of the same barley plots in 1903; the figures for phosphoric acid and potash are given in Table VIII, compared as before with the soil analyses.

All the plots receive the same manuring with nitrate of soda, but only Plots 2 and 4 receive phosphoric acid, and only Plots 3 and 4 receive potash. With phosphoric acid in the manure there is about 42 per cent. of phosphoric acid in the grain ash and 4·1 per cent. in the straw ash, dropping to 35 and 2·3 per cent. respectively when there is no phosphoric acid in the manure. The variations in the potash in the grain ash are small and not entirely in accord with the manuring. The potash content of the straw ash, however, varies greatly and in a very significant fashion; it is below 10 per cent. for Plots 1 and 2, which

[1] *Trans. Chem. Soc.* 1894, p. 115.

TABLE VIII.

Hoosfield Barley, 1903.

Plot	Manuring	Ash (pure) in Dry Matter %		In pure Ash %		In Soil (1889) %	
		Grain	Straw	Grain	Straw	Total	Citric acid soluble
	PHOSPHORIC ACID						
1 AA	Nitrate only	1·74	3·66	35·80	2·338	0·104	0·0067
2 AA	Nitrate and Phosphate; no Potash	2·27	3·71	42·27	4·179	0·165	0·0350
3 AA	Nitrate and Potash; no Phosphate	1·78	1·25	35·54	2·319	0·104	0·0082
4 AA	Complete	2·36	3·97	41·83	4·020	0·179	0·0475
	POTASH						
1 AA	Nitrate only	1·74	3·66	27·02	9·85	0·136	0·0050
2 AA	Nitrate and Phosphate, no Potash	2·27	3·71	29·93	6·12	0·142	0·0038
3 AA	Nitrate and Potash, no Phosphate	1·78	4·25	31·62	25·35	0·239	0·0350
4 AA	Complete	2·36	3·97	26·35	23·10	0·210	0·0305

receive no potash, it is above 20 per cent for Plots 3 and 4 which receive potash.

Reviewing these results with cereals there did not seem much hope that the analysis of their ash would serve as a good indicator of the capacity of a given soil to supply phosphoric acid and potash for the crops. The grain varies but little in composition, even under the extreme differences in the soil which have been established at Rothamsted by long-continued manuring in particular directions, and though the straw shows very considerable fluctuation in its potash content it is not always possible to interpret the results. Putting aside the wide seasonal variation, other factors come into play; for example an unmanured plot impoverished in all directions may yield produce with much the same ash composition as one that is rich by being equally well supplied in all directions. Again, the supplies of other bases, soda, magnesia, lime, may themselves shift the normal proportion of potash. There is nothing in the results in fact to lead one to prefer the analysis of the ash to the analysis of the soil by means of weak citric acid, except the ash of barley straw which merits further examination.

III. THE COMPOSITION OF THE ASH OF ROOT-CROPS.

From the foregoing results it is clear that one difficulty in the process comes from a lack of sensitiveness in the plant; the variations in composition of the grain of a cereal are very small, even the fluctuations in the straw, though larger, reflect but imperfectly the great differences which are known to exist between the soils.

There are however reasons which lead us to suppose that cereals would afford but imperfect test plants; no other class of plant is so well able to obtain its necessary mineral constituents from the soil provided it is supplied with nitrogen, nor does any other crop maintain its yield so well under impoverished conditions of soil. A good example is afforded by the crops grown on the Agdell field at Rothamsted; this is farmed under the ordinary four-course rotation of swede turnips, barley, clover or fallow, wheat, and is divided into three main plots, which are respectively wholly unmanured, manured with phosphoric acid and potash but without nitrogen, and completely manured, the manuring being applied to the root crop only in each rotation. The following table shows the average crop during the last three completed rotations, *i.e* after the plots had been subjected to the same treatment for the 44 previous years, and when in consequence the total impoverishment of the unmanured plot and the lack of nitrogen on the "minerals only" plot had become extreme.

TABLE IX.

	Unmanured	Minerals only	Complete Manure
	cwt.	cwt.	cwt.
*Swedes	22·1	195 4	451·6
*Barley (Total Produce)	18·8	16·4	23·4
†Clover Hay	15·6	54·5	69·6
*Wheat (Total Produce)	32·9	41·8	44·5

* The Swedes, Barley, and Wheat returns are for plots on which Clover is not grown but a bare fallow is taken in the third year of the rotation.

† Clover Crop of 1894 only.

It will be seen from this table that wheat and barley have maintained their production on the unmanured land in a remarkable fashion, for despite the extreme exhaustion of the soil on this plot the cereal crops it carries are only about 25 per cent. below the crops on the plot manured during each rotation. Nor does the mineral manuring on the

middle plot make much difference to the production of wheat and barley; as on the permanent wheat and barley plots at Rothamsted, mineral manures in the absence of nitrogen are of very little service to cereals. The clover crop feels the effect of the changed soil conditions to a much greater extent; the unmanured plot is able to grow but a very small crop less than a quarter of that on the completely manured plot. As might be expected from the power clover possesses of fixing atmospheric nitrogen, the mineral manure is almost as effective as the complete manure. With the swede turnips however the contrast is greatest; without manure they can barely grow at all, the production being only one-twentieth of that on the completely manured plot; they are also much helped by the mineral manures even in the absence of nitrogen, the production being increased nine-fold thereby. Clearly then clover, and especially swedes, are much better indicators of soil conditions than either of the cereal crops, which seem well able to obtain nutriment from the reserves that remain even in thoroughly impoverished soil. With these facts in view it seemed probable that the composition of the ash of the root crops would reflect the state of the soil in a more adequate fashion, especially as it is also possible to find root crops responsive to particular manurial constituents, *e.g.* potatoes and mangels to potash, and swede turnips to phosphoric acid.

Table X shows the proportion of potash and phosphoric acid in the ash of potatoes grown on three of the Rothamsted plots which had been under similar treatment for 25 years, compared with the total and available potash and phosphoric acid in the soil of the same plots a year later.

These results show that the variation of the composition of the ash of potatoes is not great in comparison with the very wide differences which exist in the composition of the soil, nor does it in any way agree with what we should expect from the known differences in the manurial treatment the crops have received. Again, the analyses set out in Table XI, though they belong to an earlier period—the first three years of the experiment, show that the potato ash does not vary much in composition with the very different manurial treatment to which the various plots were subject. One consideration will serve to explain this comparative constancy of composition; the potato tuber does not draw its nutriment directly from the soil, it is a secondary product of the plant's growth, a storehouse of reserve material that has been previously elaborated by the assimilating portions of the plant which deal with the raw materials of nutrition. Just as with the grain of

TABLE X. HOOSFIELD POTATOES.

Plot	Manures	Ash (pure) in Dry Matter (1896) °/o	In pure Ash of "Ware" Tubers (1896) °/o	In Soil* (1908) °/o Total	In Soil* (1908) °/o Citric acid soluble
	PHOSPHORIC ACID				
1	Unmanured	2·83	9·00	0·087	·0090
9	Superphosphate	3·29	11·46	0·167	·0569
10	Complete Minerals ..	4·35	8·88	0·178	·0582
	POTASH				
1	Unmanured	2·83	52·18	0·299	·0074
9	Superphosphate	3·29	55·12	0·454	·0132
10	Complete Minerals ..	4·35	55·86	0·458	·0443

* After growing one crop of Barley following the Potatoes.

TABLE XI. HOOSFIELD POTATOES.

Percentage Composition of the Ash of "Ware" Tubers.

Mixed Sample representing 3 years, 1876–78.

	Plot 1	Plot 3 †	Plot 9	Plot 10
Ash (Crude) in Dry Matter °/o	3·30	4·30	4·61	4·65
Peroxide of Iron and Alumina ...	0·40	0·36	0·30	0·32
Lime	2·15	1·43	1·53	1·54
Magnesia	3·60	3·25	3·33	3·41
Potash	55·50	57·48	57·77	57·58
Soda	0·19	0·12	0·32	0·53
Phosphoric acid	14·72	11·93	12·83	12·72
Sulphuric acid	8·70	5·85	5·65	6·14
Chlorine	5·32	7·90	4·70	4·74
Carbonic acid	9·18	11·11	12·87	12·44
Silica	0·67	0·59	0·49	0·56
Sand	0·54	0·44	0·29	0·40
Charcoal......................... ...	0·23	1·33	0·98	0·69
Total	101·20	101·79	101·06	101·07
Deduct O=Cl...	1·20	1·79	1·06	1·07
Total	100·00	100·00	100·00	100·00

† Plot 3. Farmyard Manure every year.

cereals the plant tends to manufacture a product of constant composition, retaining in its primary organs any excess of a particular constituent it may have received from the soil.

The potato then, notwithstanding the dependence of its growth upon the potash supply, is not likely to make a good "indicator" plant; the mangel should be better, as it does feed directly on the soil and is very dependent on an abundance of available potash.

Table XII gives the proportion of phosphoric acid and potash in ash of the mangels from four of the Rothamsted plots, all of which receive

TABLE XII.

Barnfield Mangels.

Plot	Manuring	Ash (pure) in Dry Matter* %	In pure Ash of whole plant %	In Soil (1900) % Total	In Soil (1900) % Citric acid soluble
	PHOSPHORIC ACID				
5 N	Nit. Soda + Super.	8·38	8·06	0·185	0·0453
6 N	,, + Super. and Pot.	8·05	7·78	0·176	0·0429
5 A	Amm.-salts + Super.	7·70	8·48	0·180	0·0483
6 A	,, + Super. and Pot	8·04	7·48	0·149	0·0480
	POTASH				
5 N	Nit. Soda + Super.	8·38	12·83	0·345	0·0078
6 N	,, + Super. and Pot.	8·05	29·09	0·193	0·0435
5 A	Amm.-salts + Super.	7·70	17·83	0·481	0·0116
6 A	,, + Super. and Pot.	8·04	40·55	0·629	0·0501

* From determinations made in Mixed year samples of "Roots" and of "Leaves," 6 years, 1878–83

the same amount of phosphoric acid, but only two of which, 6 A and 6 N, receive any potash. The plots receive equal quantities of nitrogen, but on the A plots in the form of ammonium salts, on the N plots as nitrate of soda. The table also shows the total and citric acid soluble potash and phosphoric acid in the soil seventeen years later, but as the manurial treatment of these plots had been practically unchanged since 1861 the difference in period is of little moment.

The phosphoric acid results are such as might have been expected, the variation is small, in accord with the fact that all the plots are heavily manured with phosphoric acid. But the variations in the potash are large and significant, the proportion rises on the nitrate of soda plots from 12·83 per cent. to 29·09 per cent. when potash had been used in the manure, and from 17·83 per cent. to 40·55 per cent. on the corresponding plots receiving ammonium salts. The soil analyses are naturally in accord, the citric acid soluble potash rises from 0·0078 per cent. to 0·0435 per cent. and from 0·0116 per cent. to 0·0501 per cent. with the use of potash in the manure. It is interesting to note in connection with these soil analyses how the long-continued use of nitrate of soda has lowered the total potash present in the soil of Plot 5 N; on this plot nitrate of soda and superphosphate form practically a complete manure and yield almost as large a crop as is obtained on Plot 6 N, whereas in the absence of both potash, and the soda to liberate it from the soil, 5 A gives a very small yield compared with 6 A.

The action of the sodium base is visible in another fashion in the ash analyses; it will be noticed that the potash content of the mangels on Plots 5 and 6 N, where nitrate of soda is used as a source of nitrogen, is considerably less than on the corresponding Plots 5 and 6 A, where ammonium salts take the place of nitrate of soda. On the non-potash plots (5 N and 5 A), the proportion of potash in the ash is 12·83 per cent. with nitrate of soda, and 17·83 per cent. with ammonium salts; on the potash plots the proportion is 29 09 per cent. with nitrate of soda, and 40·55 per cent. with ammonium salts. These differences are correlated with the amount of soda in the ash, as may be seen from the detailed analyses set out in Table XIII.

On Plot 5 N, with a deficiency of potash but an abundance of soda, the potash is as low as 12·83 per cent., the soda being up to 37·01 per cent, while on the corresponding Plot 5 A, equally deficient in potash but short also of soda, the yield is deficient for want of potash, but the proportion of potash to soda is about equal.

With Plot 6 N, where there is an excess of both bases, the plant takes up rather more potash than soda, 29 per cent. against 23 per cent., while on Plot 6 A, with abundance of potash but no soda, the plant contains 40·55 per cent. of potash against 9·69 per cent. of soda.

It is significant that the sum of the alkalis is practically constant where either one or both are obtainable, as on Plots 5 N, 6 N, and 6 A, but falls in the case of 5 A, where neither alkali is present in the

manure, its place being taken by an increased amount of lime, of which a large excess is available on all plots.

TABLE XIII.

Barnfield Mangels.

Percentage Composition of Pure Ash of Whole Plant.

	Mixtures 6 years, 1878–83			
	5 N	6 N	5 A	6 A
Ferric oxide	0·62	0·63	0·93	0·64
Lime	5·53	5·63	16·29	7·88
Magnesia	2·33	2·22	4·43	3·09
Potash	12·83	29·09	17·83	40·55
Soda	37·01	23·05	19·54	9·69
Phosphoric acid	8·06	7·78	8·48	7·48
Sulphuric acid	4·59	4·44	4·46	3·38
Chlorine	4·74	4·30	14·92	15·03
Carbonic acid	24·34	22·64	15·51	14·49
Silica	1·01	1·19	0·97	1·16
Total	101·06	100·97	103·36	103·39
Deduct O = Cl	1·06	0·97	3·36	3·39
Total	100·00	100·00	100·00	100·00

TABLE XIV.

Percentage of Alkalis in Ash of Mangel.

Plot	5 N	6 N	5 A	6 A
Manuring	Soda, no Potash	Soda and Potash	No Alkali salts	Potash, no Soda
Potash %	12·83	29·09	17·83	40·55
Soda %	37·01	23·05	19·54	9·69
Sum of Alkalis	49·84	52·14	37·37	50·24
Lime %	5·53	5·63	16·29	7·88

These figures have an important bearing upon the question under consideration; there is a difference of more than 11 per cent. in the proportion of potash in the mangel ash in the two cases where the soil contains an excess of potash, and there is a similar difference of 5 per cent. in the two cases where potash is deficient in the soil, these differences being due to the amount of soda present. Any abundance of soda acts as a diluent and reduces the proportion of potash in the mangel ash, even though the plant may have an excess of potash available. In consequence the normal proportion of potash in the ash of the mangel will vary with factors other than the potash content of the soil, especially will the presence or absence of sodium salts in the manure have a marked effect. From this we may conclude that if an ash analysis is to be used to indicate the manurial requirements of the soil, it is necessary that the roots analysed shall have been grown on an unmanured piece of the land in question.

IV. THE COMPOSITION OF THE ASH OF SWEDES AND MANGELS GROWN ON VARIOUS SOILS.

In accordance with the conclusions thus derived an attempt was made in 1903 to procure swedes and mangels grown on unmanured plots from field trials in various parts of the country so as to obtain a comparison of the ash and soil analyses with the results of actual experiment with the fertilisers in question.

Unfortunately in 1903 very few extended field trials were going on which would provide the right kind of material; Professor J. Percival, of Reading, obtained for me a number of samples from plots under his control, all of which showed great response to phosphatic manures; and through the kindness of Professor D. A. Gilchrist and Mr C. Bryner Jones, of the Durham College of Science, I was also provided with roots from land at Cockle Park and at Hamsterley, whose response to phosphatic and potash manuring was well known.

Table XV shows the results obtained with nine samples of swedes, all drawn from unmanured plots, except the Bisley sample, which was taken from an ordinary farm crop on the Bagshot Sand formation, the field being in high condition and manured with dung.

Considering first the phosphoric acid results in the field experiments, soils 1 to 6 show a considerable response to phosphatic manuring, whereas soils 8 and 9 seem able to supply ordinary crops with this constituent, the Arborfield sample No. 7 being rather a doubtful case.

TABLE XV.

Swedes, 1903.

	Ash (pure) in Dry Matter %	In pure Ash %	In Soil % Total	Citric acid soluble	Extra Citric acid used	Calcium Carbonate
PHOSPHORIC ACID						
1. Kirtlington	4·39	8·96	0·256	0·0013	0·0199	9·5
2. Wallingford	3 87	9·10	0·175	0·0014	0·0129	6·73
3. Hamsterley (Brierly Hill)	4·03	10·56	0·176	0·0203	—	0·62
4. Chipping Norton	4·55	10·91	0·187	0·0052	0·0123	4·0
5. Shenington	5 00	11·18	0·840	0·0128	0·0135	0·31
6. Blandford	3·14	11·81	0·121	0·0088	0·0080	1·68
7. Arborfield	3·75	12·77	0·049	0·0073	—	
8. Bisley	4·60	15·01	0 061	0·023	—	
9. Cockle Park	3·25	15·85	0·144	0·0324	—	
POTASH						
6. Blandford	3·14	22·82	0·340	0·0060		
9. Cockle Park	3·25	32·00	0·144	0·0112		
2. Wallingford	3·87	38·86	0·404	0·0057		
3. Hamsterley (Brierly Hill)	4·03	40·37	0·248	0·0210		
7. Arborfield	3·75	40·66	0·237	0·0227		
8. Bisley	4 60	40·81	1·40	0·027		
5. Shenington	5·00	43·36	0·287	0·0155		
1. Kirtlington	4·39	43·62	0·621	0·0072		
4. Chipping Norton	4·55	44·49	0·377	0·0192		

Putting this aside it will seem that the proportions of phosphoric acid in the ash of Nos. 1 to 6, which respond to phosphatic manuring, lie between 8·96 per cent. and 11·81 per cent., whereas the two not requiring phosphatic manuring show over 15 per cent. of phosphoric acid in the ash of the swedes. The soil analysis agrees in the main; the citric acid soluble phosphoric acid is exceptionally low for Nos. 1 and 2, which give extremely low proportions of phosphoric acid in the ash; and none of the other soils (except No. 3 with 0·02 per cent. citric acid soluble phosphoric acid) would be taken as properly provided with available phosphoric acid for a root crop, until the soils 8 and 9, which

are rich in citric acid soluble phosphoric acid, are reached. As some of these soils contained much carbonate of lime, determinations of this constituent were made and extra citric acid to neutralise it was added before making up the solvent to the 1 per cent. strength[1]. The results thus obtained are set out alongside those obtained in the usual way; with the chalky soils the extra citric acid naturally results in the solution of a much greater quantity of phosphoric acid, but the figures yielded by the ordinary 1 per cent. solution of citric acid are far more in accordance with the field experiments. The Shenington soil, No. 5, is a case not often met with; it contains as much as 0·84 per cent. of phosphoric acid, of which 0·0128 per cent. is soluble in citric acid, the latter being a fair amount for an arable soil, although it bears a very low proportion to the total phosphoric acid present. The explanation is to be found in the fact that the soil is derived from the Marlstone (Lower Lias) and is largely made up of hydrated ferric oxide, containing as much as 28·16 per cent. F_2O_3 in the air-dried soil, whereas ordinary soils only yield 2—4 per cent. to hydrochloric acid. This tends to show that an excess of ferric oxide, like calcium carbonate, keeps the soil phosphoric acid in an undissolved state and the soil water low in phosphoric acid, so starving the crop as regards this particular constituent.

The results with potash are set out in Table XV; of these soils only Cockle Park and Blandford are reported as responsive to potash manuring, and these are the two in which the percentage of potash in the ash falls much below 40 per cent. In this respect the results obtained by analysing the ash are more in accord with the field experiments than those obtained by the analysis of the soil. The citric acid soluble potash of the first two soils in the table is certainly low, lower than would be considered desirable for root crops, but two of the other soils give still lower results, which are not reflected in either the field experiments or the analyses of the ash. One of the soils from Bisley gives a very exceptional amount of total potash, especially considering that it is a light sand; however, the subsoil yielded even a higher figure, due to a glauconitic layer in the sandstone from which the soil is derived at this spot. An additional analysis of swedes from a manured plot at Hamsterley gives a further illustration of the way a nitrate of soda manuring will depress the potash content of the roots.

Unfortunately I was not able to procure any series of mangels from soils of known character; a few cases, however, served to give some idea

[1] Cousins and Hammond, *Analyst*, 1903, p. 238.

TABLE XVI.

Swedes from Hamsterley.

	Phosphoric Acid °/o in Ash	Potash °/o in Ash
Plot 1. Unmanured	10·56	40·37
,, 6. Manured with Nitrate of Soda and Superphosphate...	11·59	38·97

of the normal composition of the roots for comparison with the Cockle Park mangels, grown on soil known to be in need of potash manuring.

The Cockle Park results for the three kinds of roots examined, potatoes, mangels, and swedes, are set out in Table XVII; the first

TABLE XVII.

Roots from Cockle Park, 1903.

	Average of others	Cockle Park		
			In Soil	
	In Ash °/o	In Ash °/o	Total °/o	Citric acid soluble °/o
PHOSPHORIC ACID				
Potatoes	15·93	19·44	0·16	0·035
Mangels	8·25	11·27	0·21	0·048
Swedes	11·29	15 85	0·14	0·032
POTASH				
Potatoes	59·45	54·05	0·21	0·018
Mangels	44·77	35·14	0·33	0·017
Swedes	41·74	32·00	0·14	0·011

column shows the average proportion of the phosphoric acid and potash in whatever other samples were available for 1903, the next three columns show the proportions in the ash of the Cockle Park roots and in the soil in which they were respectively grown.

The various results are in very satisfactory accord. It is known that the soil shows no specific need for phosphatic manuring and the proportion of phosphoric acid in each of the three roots is well above the average; the citric acid soluble phosphoric acid in the soil averages 0·038 per cent., a high figure. The soil is also known to need potash manuring; this is well brought out in the ash analyses, the ash of the mangels in particular showing a very low proportion of potash. The citric acid soluble potash in the soil averages 0·015 per cent., a figure not much below the amount usually found in arable soils.

Looking at these results as a whole the analysis of the swede ash indicates the character of the soil no better than, if so well as, the amount of citric acid soluble phosphoric acid, but the state of the soil as regards potash is much more readily interpreted from the composition of the mangel ash than from the amount of potash dissolved by the weak solution of citric acid. The determinations would seem to show that by the analysis of the ash of swedes and mangels grown on a given soil the manurial requirements of that soil, especially as regards potash, could be very well determined. But before such a method can be recommended as displacing the ordinary methods of analysing the soil, other test plants must be found. Swedes and mangels only answer the required purpose if they have been grown on an unmanured plot of the land in question, since manuring, even with substances other than those under examination, may quite disturb the composition of the ash. But it would be impossible in practice to obtain samples of swedes or mangels grown without manure of some kind, nor is it feasible to wait until these crops could be grown on specially unmanured land. Hence if the method of analysis by the plant is to replace that of direct analysis of the soil, some test plant must be found which grows pretty universally on all soils, in fact some weed of arable land that would be always available. It must be a weed fairly sensitive to soil conditions, resembling the root crops rather than the cereals, and its normal composition must be established at a particular stage of growth. Then a large number of analyses will be wanted of this plant grown under various soil conditions, until the extent of the ordinary fluctuations in its ash composition has been determined, so as to afford a basis for the interpretation of future determinations made on the ash of the same weed gathered from the soil under examination. It is in the direction of finding such a test plant that I am now continuing the work. The ash of barley straw also merits a little further consideration as a test material.

General Conclusions.

1. The proportion of phosphoric acid and of potash in the ash of any given plant varies with the amount of these substances available in the soil, as measured by the response of the crops to phosphatic or potassic manures respectively.

2. The extent of the variation due to this cause is limited, and is often no greater than the variations due to season, or than the other variations induced by differences in the supply of non-essential ash constituents—soda, lime, etc.

3. The fluctuations in the composition of the ash are reduced to a minimum in the case of organs of plants, which, like the grain of cereals, or the tubers of potatoes, are manufactured by the plant from material previously assimilated.

4. The composition of the ash of the cereals is less affected by changes in the composition of the soil than is that of root crops like swedes and mangels.

5. The composition of the ash of mangels grown without manure on a particular soil gives a valuable indication of the requirements of the soil for potash manuring. Similarly the phosphoric acid requirements are well indicated by the composition of the ash of unmanured swedes, though in this case determination of the citric acid soluble phosphoric acid in the soil gives even more decisive information.

6. Pending the determination of phosphoric acid and potash "constants" for some test plant occurring naturally on unmanured land the interpretation of soil conditions from analyses of plant ashes is not a practicable method by which chemical analysis of the soil can be displaced.

VARIATION IN THE CHEMICAL COMPOSITION OF THE SWEDE.

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THAT swedes are better feeding materials under some conditions than under others is more or less generally recognised; the suggestion of controlling these conditions is perhaps not new, but little of practical importance has been achieved in this direction. About five years ago the subject was considered at the Durham College of Science (now Armstrong College), Newcastle-upon-Tyne, and experiments were started which have been repeated and added to every season. The object of these investigations was to form a list of the different varieties of swedes in order of merit. Incidentally other points of interest have arisen, and are dealt with in the following pages. The results of these experiments have been published each year in the Annual Report of the Agricultural Department of the College, but a review of the work done seems of sufficient general importance to prove interesting to a larger circle of readers.

FEEDING VALUE AND "DRY MATTER."

It would be quite impracticable to carry out feeding experiments of a sufficiently extended range, to show directly the relationship between the live-weight increase produced by consuming swedes grown under all the varying conditions which occur in actual farming practice. It is possible, however, to find a simple chemical test which can indicate, approximately, the feeding value.

In order to find such a test a feeding experiment was carried out at the Experimental Farm of the Northumberland County Council[1], in

[1] Annual Report, 1902, and Bulletin, 1904.

which sheep were fed on rations exactly alike, except that some sheep received one kind of swede and some another kind, the swedes as well as the other foods being subjected to chemical analysis. The results of this experiment show that there is a very direct relationship between the feeding value and the amount of total "dry matter" in the swedes. Other experiments with cattle have yielded similar results. It is difficult, however, to trace any relationship between the feeding value of the roots, as determined by direct feeding experiment, and the amount of any other constituents, except the total "dry matter" and the carbohydrates. Since the amount of the carbohydrates is merely a difference figure obtained from the dry matter by subtracting the other constituents really determined, it is probable that the chemical determination of the "dry matter" is the most satisfactory means of determining the relative feeding value of swedes.

Purely theoretical considerations lead to the same conclusion. The water in the swede can have no value in itself, and all the other constituents are so easily digestible that no great error would result if the dry matter were considered to be completely digested.

As regards the different constituents of the dry matter, the amount of the carbohydrates is so large in comparison with the nitrogenous substances, that the effect of differences in the amount of the latter would be obliterated, supposing that the other foods used with the swedes supplied enough nitrogenous substances for the needs of the animal. If it were possible to obtain swedes with a large proportion of albuminoids, or if it were possible to fatten stock with little albuminoids in the other foods used, then it is unlikely that the determination of the "dry matter" by itself would be a sufficient guide to the feeding value of the swedes.

A point which is not quite certain from theoretical grounds is the relative feeding value of the sugar, and the other constituents included under the term carbohydrates. The feeding trial referred to above shows that there is probably no great difference in feeding value between sugar and other carbohydrates.

It must be pointed out that the foregoing remarks as to relative feeding values apply only when swedes are compared with swedes.

METHODS OF ANALYSIS.

Before the above experiments had been carried out a good many trials had been made on different methods of sampling and analysis. As a general result of these experiments I came to the conclusion that the best way of sampling was to take a core through the swede with an auger. It is very necessary that the core should go as nearly through the centre as possible, but I could not find any great difference between cores taken in different directions. The diameter of the auger should be small in comparison with that of the root; otherwise too great a proportion of the centre of the root would be taken. I originally came to the conclusion that the smallest number of swedes which must be sampled in order to obtain results representing a whole crop was 25, but experience has shown that this number is too small, and that samples taken from less than 100 roots give untrustworthy results. Even with this larger number it is better to have the results of three or four analyses and to average them before coming to any definite conclusions. A study of the figures in the final table will bear this out.

It is necessary that the analysis should be started before the samples have had time to dry; and it is difficult to chop the cores up or do anything else to them except weigh them at once and dry them. For drying the cores it is necessary to employ low temperatures, partly because it is almost impossible to get concordant results at high temperatures, and partly because at high temperatures the sugar is altered and in part decomposed, thus rendering the dried portions of no use for subsequent analysis. The limits I have adopted are 50° to 60° C., averaging as near 55° as possible. For this purpose special ovens were built, a complete description of which has already been published[1].

It is important to remember this temperature when comparing these results with the investigations of other workers, who usually dry their substances in a steam or water oven, at from 85° to 98° C., a simple convention having no real meaning excepting general convenience.

METHODS OF ELIMINATING DISTURBING CAUSES.

For the purpose of placing the different varieties of swedes in order of merit as regards feeding value, it is necessary to eliminate the effects of other factors than variety. This has been done in part experimentally, by growing swedes under conditions such that the other

[1] *Journal of the Society of Chemical Industry*, 1902, p. 1514.

causes are inoperative, and in part, mathematically, by calculating the extent of the disturbance due to other conditions and making the necessary correction.

CAUSES OF VARIATION IN COMPOSITION.

Before we can eliminate the effect of factors other than "variety" we must ascertain to what other factors variation is due. For this purpose we may imagine the percentage of dry matter (A) found by analysis to be the sum of a number of terms a, b, c ..., and we get the expression $A = a + b + c$ ..., in which we require to evaluate the terms a, b, c ..., each depending on one factor of variation[1].

The general aim of the following enquiry is to separate the causes of the variation in the composition of swedes under the heads of individuality, size, manuring, variety, season, soil, district, etc.

It is necessary to reduce the work to some compact form, and the method of treatment used enables the work on varieties to be represented in a small table (see Table VIII).

In some cases it will be necessary to exercise caution in drawing conclusions from the earlier experiments, as the importance of having a large number of swedes to the sample was not at first fully recognised.

The individual root. Samples taken from roots grown under the same conditions show considerable difference in the amount of sugar and dry matter contained in them. This can only be due to individual idiosyncrasy. In the case of sugar I found a variation of over 4 per cent.; and in the case of "dry matter" Wood and Berry[2] found a variation of about 7 per cent. These variations are greater than those due to any other cause. Considering these very large variations it should be obvious that a large number of roots must be cored in order to obtain a representative sample.

Size. In 1899 Monarch swedes were grown at Cockle Park under different systems of manuring, and these were so sampled that 25 large roots and 25 small roots were selected from each plot (Table I). The large ones were about 5 to 6 pounds in weight and the small ones 2 to 3 pounds. The sampling was done by slicing, as at this date the advantage of the coring method of sampling had not been proved, and as explained above 25 roots were then thought sufficient to give a representative sample. The variations due to size ranged from 1·75 to

[1] "Variation" is used to express "variation (or difference) in the percentage of dry matter in swedes"; "variety" to express "the variety (or kind) of swede."

[2] *Cambridge Philosophical Society's Proceedings*, March, 1903.

TABLE I.

Composition of large and small Swedes. 1899.

Monarch Swedes.

	A F.Y. Manure		B Artificial Manure		C F.Y. Manure and Artificials		D F.Y. Manure and Artificials		Averages				Average	
	Small	Large	Small	Large	Small	Large	Small	Large	A	B	C	D	Small	Large
Dry matter %	11·41	9·66	10·77	10·37	10·64	9·99	10·55	9·59	10·53	10·57	10·31	10·07	10·84	9·90

A, B, and C were grown on Cockle Park, Northumberland.

D, grown at Longniddry, East Lothian, with same manures as C.

0·40 per cent. dry matter, the small ones being richer, but as the number of roots taken was small, part of this difference might be due to errors of sampling. The average, however, representing 100 large roots and 100 small roots, may be trusted, and shows that the small roots contained 0·94 per cent. more "dry matter" than the large roots. This amount of variation is similar to that found by other investigators.

Variation due to size therefore, although of importance, is less than that due to other causes It may be eliminated by taking samples of a middle size, leaving out the very small and very large roots, an operation which introduces the personal equation of the man who samples. In the investigations on the other causes of variation, the effect of size has been minimised in this way, and by averaging results, in different years, in different places, and from roots sampled by different persons, it should be eliminated.

Manures. Table I shows the effect of different manures as well as the effect of different sizes on the amount of "dry matter" in the swede. Columns A, B, and C under "Averages," in which are given the percentage of "dry matter" for average-sized swedes grown at the same place, Cockle Park, in the same year, 1899, of the same variety, Monarch, but with different manures, give information on this subject. The maximum effect, that is the difference between columns B and C, is 0·26 per cent.; a small variation compared with that due to other causes.

In Table II are collected the results of other analyses of swedes

grown at various places with various manures. These differences in manuring are extreme and would never occur in practice (many of the experimental plots gave very small yields), yet the average effect of even such extreme manuring is only a small one, viz. 0·60 per cent. between the roots grown respectively with no manure and with a complete artificial manure.

In comparing different varieties, I have always compared varieties grown side by side at the same place, so that the differences in composition due to variety cannot contain any error due to the effect of the manure. The manures used at Cockle Park are the standard dressings of the College of Science, and do not differ from year to year, hence the variations due to season contain no error due to different manures. In comparing the results obtained from swedes grown at different stations in the North of England, the error introduced from neglecting variation due to manures may be appreciable, but will be all included in the variation due to "soil and district," a figure to which I do not attach much importance.

? See table II.

TABLE II.

Swedes.

Variation in Composition due to Manures at seven stations in the County of Durham.

Station	Dry Matter %				
	Manures				No Manure
	Complete Artificial	No Nitrogen	No Phosphates	No Potash	
Cleatlam	10·17	10·48	11·18	10·83	11·61
Neasham Grange	9·95	10·85	10·55	10·48	10·93
Medomsley E.	12·04	12·60	12·36	12·35	12·60
,, W.	10·88	12·05	11·11	12·08	12·24
Newlands Haugh	9·94	9·57	10·45	10·39	9·69
Sherburn	12·51	11·19	10·15	10·44	12·49
Birtley	11·34	11·44	11·63	11·29	11·51
Average	10·98	11·18	11·06	11·12	11·58

The variety. This cause of the variation in composition is an important one, not only on account of its magnitude, but also because

the variety he sows is under the complete control of the farmer. Yield per acre is a very important consideration in the choice of a variety; but it is quite a different issue from chemical composition and feeding value and must be experimented on separately. Judging from the figures obtained at Cockle Park and from those published by other investigators, it appears unlikely that the yield per acre of any variety will prove as uniform as the amount of dry matter. The results of the investigations on the variation in composition due to variety are so constant that it is possible to average them all wherever the experiments have been carried out. In Table III are given the results of seven varieties of swedes grown at Cockle Park. The last column in the table gives the excess or deficiency of each variety in dry matter as compared with the average—11·23 per cent. These figures in the last column I propose to call the variety factor (v).

TABLE III.

Percentage of Dry Matter in Swedes grown at Cockle Park, Northumberland.

	1900	1901	1902	Average of years	Equals 11·23
Sutton's Crimson King	11·48	10·47	11·57	11·17	−0·06
Dickson, Brown and Tait's Best of All	10·83	9·63	12·13	10·86	−0·37
Drummond's Stirling Castle	11·37	10·58	11·85	11·27	+0·04
Kent and Brydon's XL All	10·47	9·92	11·23	10·54	−0·69
Fell's Bronze Top	12·38	10·41	12·48	11·78	+0·53
Webb's Arctic...	11·77	10·87	12·39	11·68	+0·45
Carter's Holborn Kangaroo	11·73	10·38	11·84	11·32	+0·09
*Average of varieties	11·43	10·32	11·93		
Average of seven varieties for three years				11·23	
Effect of season (+11·23 in each year)	+0·20	−0·91	+0·70		

Season. In the last line of Table III is given the variation of the average figure for each season from the general average of all seasons. This figure in the bottom line I propose to call the season factor (s).

* See Table X.

Verification of results. The above analytical treatment may be made synthetical. In the expression $A = k + v + s$, A, the percentage of dry matter, may be calculated by adding together the constant, k (11·23 for Cockle Park), the variety factor, v, and the season factor, s. As k, v, and s, are all average results, the percentage of dry matter by calculation could only agree with the percentage found by chemical analysis, if the values for k, v, and s, were practically constant.

From the data set out in Table III we are now in a position to calculate what the composition of any variety in any season at Cockle Park ought to be, and to compare the results so obtained with that found by direct chemical analysis. For example in Table IV, Crimson King, 1900, calculated percentage dry matter

$$= 11{\cdot}23 - {\cdot}06 + {\cdot}20 = 11{\cdot}37.$$

If the two sets of figures so obtained agree well with one another, then the method of calculation must be correct. But what is a good agreement? If the two sets of figures "calculated" and "found" agree with one another as well as the duplicates of actual analyses, then the agreement is certainly a good one. I find that the average difference between duplicates of the samples analysed in 1902 was 0 31, between duplicates of all the samples to date 0 38.

For the sake of round numbers we can take 0·30 as the limit of good agreement. Of the 24 samples of swedes grown at Cockle Park and analysed (see Table III), there were 5 samples in which the difference between the duplicates exceeded 0 30; on comparing the "calculated" and "found" amounts as given in Table IV, it will be seen that the "calculated" amounts differ from the "found" amounts by more than 0·30 on only 5 occasions out of the 24. The agreement between "calculated" and "found" amounts is, therefore, a very good one; the method of investigation is justified and the figures obtained are verified.

Soil and District. These experiments have also been carried out at other places in the North of England besides Cockle Park (see Table V). The average of several varieties grown at different places differs from the averages of the same varieties grown at Cockle Park. Owing to the fact that the seven standard varieties were not all grown at the other stations, the variation in composition due to soil and district could not be calculated in exactly the same way as the variety factors at Cockle Park (Table III). For example, the four varieties grown at Neasham Grange (Table V) average 11·84 per cent. dry matter,

TABLE IV.

Showing Agreement between the Calculated and Found Amounts of Dry Matter in Swedes grown at Cockle Park, Northumberland.

	1900		1901		1902		
	Calc.	Found	Calc.	Found	Calc.	Found	
	%	%	%	%	%	%	%
Crimson King	11·37	11·48	10·26	10·47	11·87	11·57	...
Best of All	11·06	10·83	9·95	9·63	11·56	12·13	11·55
Stirling Castle.....	11·47	11·37	10·36	10·58	11·97	11·85	...
XL All	10·74	10·47	9·63	9·92	11·24	11·23	11·58
Fell's Bronze Top	11·96	12·38	10·85	10·41	12·46	12·48	...
Arctic	11·88	11·77	10·77	10·87	12·38	12·39	12·22
Kangaroo	11·52	11·73	10·41	10·38	12·02	11·84	...

TABLE V.

Percentage of Dry Matter in Swedes grown at various stations in the Counties of Northumberland and Durham in 1902.

	Portrack Grange, Stockton	Kelloe Hall, Coxhoe	Neasham Grange, Darlington	Sherburn Colliery	Grange Hill Bishop Auckland	Riffington, Cornhill-on-Tweed	Red Barns, Bishop Auckland	Cleatlam, Staindrop	Raby, Staindrop	Eshott, Felton	Billingham, Stockton
Crimson King	..	...	11·64	11·45	11·76	12·37	...	...	...	...	...
Best of All	...	12·06	11·30	...	...	. .	12·27	12·33	..	. .	12·92
Stirling Castle... ..	11·78	...	...	...	12·75	...	...	...	12·73	13·30	...
XL All	..	...	11·77	12·18	...	12·04	...	11·90	12·36	..	...
Fell's Bronze Top	12·03	...	...	...	13·19	...	. .	...	...	14·09	...
Arctic	...	12·62	...	...	12·02	...	12·79	...	...	...	13·62
Kangaroo	.	...	12·65	11·60	12·25	13·66	...	...	...	...	...
Prize Winner	...	12·07	...	...	12·25	...	12·49	...	...	...	13·20
Darlington	11·10	...	...	...	11·48	...	...	12·35	12·70	12·56	...

and the same four varieties grown at Cockle Park for three years average 10·97 per cent. dry matter (Table III) to which must be added the season factor +0·70[1], making 11·67 per cent. The excess of Neasham Grange over Cockle Park is (11·84 − 11·67) = + 0·17. In this way Table VI has been constructed.

[1] A shorter calculation is $A = k + v + s = 11{\cdot}23 + \frac{-{\cdot}06 - {\cdot}37 - {\cdot}69 + {\cdot}09}{4} + {\cdot}70 = 11{\cdot}67$.

TABLE VI.

Variation in the Percentage of Dry Matter in Swedes due to the Farm on which they are grown.

Station	1902		1903	
	$11{\cdot}23+s+f$	f	$11{\cdot}23+s+f$	f
Cockle Park, Morpeth	11·93	standard	11·67	standard
Portrack Grange, Stockton	11·48	−0·45	11·08	−0·59
Kelloe Hall, Coxhoe	12·14	+0·21		
Neasham Grange, Darlington	12·10	+0·17		
Sherburn Colliery, Durham	11·99	+0·06	12·15	+0·48
Grange Hill, Bishop Auckland	12·07	+0·14		
Riffington, Cornhill-on-Tweed	12·91	+0·98		
Red Barns, Bishop Auckland	12·33	+0·40		
Cleatlam, Staindrop	12·58	+0·65		
Raby, Staindrop	12·85	+0·92	11·25	−0·42
Eshott, Felton	13·16	+1·23	12·12	+0·45
Billingham, Stockton	13·15	+1·22		
Denton Grange West, Heighington			13·03	+1·36

The variations in percentage of dry matter, due to the farm on which the swedes were grown, do not appear to be the same in different seasons. The extent of the variation is important, 1·68 per cent. in 1902 and 1·95 per cent. in 1903[1]. I do not, however, propose to discuss this cause of difference in composition at present. The figure obtained may be used for abbreviating calculations, but its precise meaning may be left over; for want of a better name I call it the farm factor (f).

To trace the variety factor in the different counties I have constructed Table VII. The data for calculating the figures in the columns for Northumberland and Durham are given in Table X; the variety factors for Norfolk are calculated from the results published by Wood and Berry[2]. In calculating the Norfolk results I first averaged the three farms and then subtracted from each average such a number (12·08), that the average variety factor of the six varieties tested is the same (−0·17) in Norfolk and in the North of England. In only one variety, Crimson King, do the variety factors in different counties differ by more than 0·30, yet the extreme difference due to variety is 1·85. The difference between Northumberland and Durham is very slight. The variety factors, therefore, may be applied over large areas.

[1] $+1{\cdot}23-(-0{\cdot}45)=1{\cdot}68$ and $+1{\cdot}36-(-0{\cdot}59)=1{\cdot}95$.

[2] *loc. cit.*

TABLE VII.

Showing that the relative merit of varieties of Swedes is fairly uniform over a large area.

Variety of Swede	Variety factors in the County of		
	Northumberland	Durham	Norfolk
Dickson, Brown and Tait's Best of All	−0·31	−0·23	−0·31
Fell's Bronze Top	+0·77	+0·70	+0·62
Kent and Brydon's XL All	−0·67	−0·55	−0·61
Webb's New Arctic	+0·15	+0·24	+0·39
Kent and Brydon's Darlington	−0·29	−0·29	
Sutton's Crimson King	−0·35		−0·01
Garton's Model	−0·78		−1·08

THE CONSTANT AND THE FACTORS.

On page 96 I gave the expression $A = k + v + s$, where A was the amount of dry matter in the swedes, k a constant, 11·23, and v and s the variety and season factors respectively. The constant k was determined from only three years' experiments, a quite insufficient amount. A recalculation of k will give

1900	11·43 °/ₒ	dry matter in average swede ($k + s$) (Table III)
1901	10·32 „	„ „ „ „ „ „
1902	11·93 „	„ „ „ „ „ „
1903	11·67 „	„ „ „ „ (Table X)
1904	14·96 „	„ „ „ „ „ „
Mean	12·06 „	„ „ „ „ „ „

It is probable that the average will be higher than 11·23, but the last two years have been so abnormal that it is useless changing the figure 11·23 until further experiments have been carried out.

The factor v depends on the subtraction of $k + s$ from A. The figure A is a single analytical determination and is liable to error, the expression $k + s$ is an average of many results and is not likely to be far from the truth. An average of several determinations of v will give a reliable result.

The factor v is supposed to represent the variation from the general

average of a "variety," which can only be defined for the purpose of these investigations as dependent upon the label on the outside of the packet in which the seed was bought. From the practical point of view this unsatisfactory definition does not matter, since the farmer must buy his seed in the same way. The character of varieties is quite certain to change in process of time and therefore the average of the seven standard varieties must change.

The conditions under which the seed was grown will probably influence the amount of dry matter in the swede; a study of the results will show that these fluctuations are probably of a temporary nature since the averages of five or more determinations of the variety factor v seem fairly constant (Table X).

In the case of Drummond's Extra Improved Purple Top there is, however, some evidence of a progressive increase.

The factor s is the difference between k and $k+s$, both of which are averages of large numbers of experiments. The factor k, however, can only be correctly determined after at least ten years' experiments, so that the season factor cannot be determined exactly at present. The relative effect of season can, however, be shown by the season factor whether the fundamental constant k is correct or not. The extreme seasonal variation found up to the present time is 4·64 per cent.—14·96 in 1904 and 10·32 in 1901. Further experiments may show an even greater range; and it is probable that season will rank as next in importance to individuality as a cause of variation.

How much of this seasonal variation is really due to meteorological conditions is uncertain. The time of sowing may affect the results, but then the time of sowing is itself to some extent dependent on meteorological conditions.

Composition of the Average Swede.

In feeding experiments it has sometimes been customary to assume an average composition for swedes. The above figures show that the average swede at Cockle Park during the last five years has averaged 12·06 per cent. of dry matter, and from Table VI it can be seen that the average farm in the North of England grows swedes rather richer than Cockle Park does. The average of all the farms tested is 0·46 more than Cockle Park in 1902, and 0·21 more than Cockle Park in 1903. Taking the mean (0·33), we find[1] 12·39 per cent. dry matter as the

[1] $12·06+0·33=12·39$.

average for the North of England. Whether further experiments will increase or decrease this figure cannot be foretold, but it is certain that the figures commonly given in the text-books are too low.

CONCLUSION.

The results of all my experiments up to date are included in Table X, which contains all analyses except those of varieties which have been tested less than three times, and those individual analyses in which the duplicates differ by more than 1 per cent. There have been only three cases of such a large error, a small proportion of accidents which it is quite legitimate to ignore.

These analyses and calculations now enable us to draw up a list of varieties in order of merit (see Table VIII). This list, like a list already published[1], gives an order of merit solely depending upon the percentage of dry matter; the new list is, however, deduced from a much larger number of analyses of swedes grown at many different places and over a greater range of years.

For the sake of comparison I append the list first published (Table IX).

It only remains for me to thank members of the Durham College of Science, especially the past and present members of the agricultural staff, and the proprietors and managers of the farms named, for the facilities and kind assistance which they have at all times given me.

[1] Report of the Agricultural Department of the Durham College of Science, Newcastle-upon-Tyne, for 1901, p. 97.

TABLE VIII.

Order of Merit of Varieties of Swedes according to the percentage of total Dry Matter.

AVERAGE OF ALL RESULTS TO END OF 1904.

+0·7	Fell's Bronze Top
+0·3	Webb's Imperial
+0·2	Carter's Prize Winner, Carter's Holborn Elephant, Carter's Holborn Kangaroo, Drummond's Stirling Castle, Webb's New Arctic
+0·1	Drummond's Extra Improved Purple Top
0·0	Fell's Halewood Bronze Top
−0·3	Dickson, Brown and Tait's Best of All, Kent and Brydon's Darlington Bronze Top, Sutton's Crimson King
−0·6	Kent and Brydon's XL All
−0·8	Garton's Model Bronze Top

TABLE IX.

Order of Merit of Varieties of Swedes according to the percentage of total Dry Matter

	1900	1901
Best	Fell's Bronze Top (12·38)	Webb's New Arctic (10·87)
	Carter's Elephant	Carter's Elephant
	Webb's New Arctic	Stirling Castle
	Carter's Kangaroo	Crimson King
	Crimson King	Fell's Bronze Top
	Stirling Castle	Carter's Kangaroo
	Extra Improved	Monarch
	Monarch	Extra Improved
	Best of All	XL All
	Model	Best of All
Worst	XL All (10·47)	Model (9·46)

TABLE X.

Variety and Station where grown	Dry Matter % Duplicates		Difference between duplicates	Average	11·23 +s +f	Variety factor
				A	*	v
Carter's Holborn Elephant.						
Cockle Park 1900	11·83	12·13	0·30	11·98	11·43	+0·55
Cockle Park 1901	10·23	11·10	0·87	10·66	10·32	+0·34
Cockle Park 1904	14·78	14·50	0·28	14·64	14·96	−0·32
Eshott 1903	11·88	12·58	0·60	12·23	12·12	+0·11
Sherburn Colliery ... 1903	11·98	11·83	0·15	11·90	12·15	−0·25
Eshott 1903	12·67	12·66	0·01	12·66	12·12	+0·54
Average for North of England, all results						+0·16
,, ,, ,, ,, less highest						+0·08
,, ,, ,, ,, ,, lowest						+0·26
Carter's Holborn Kangaroo.						
Cockle Park 1900	11·57	11·89	0·32	11·73	11·43	+0·30
Cockle Park 1901	10·33	10·44	0·11	10·38	10·32	+0·06
Riffington 1902	13·78	13·54	0·24	13·66	12·91	+0·75
Cockle Park 1902	11·80	11·88	0·08	11·84	11·93	−0·09
Neasham Grange ... 1902	12·61	12·68	0·07	12·65	12·10	+0·55
Sherburn Colliery ... 1902	11·89	11·31	0·58	11·60	11·99	−0·39
Average for North of England, all results						+0·20
,, ,, ,, ,, less highest						+0·09
,, ,, ,, ,, ,, lowest						+0·31
Carter's Prize Winner.						
Cockle Park 1901	10·90	11·16	0·26	11·03	10·32	+0·71
Cockle Park 1902	11·61	11·84	0·23	11·72	11·93	−0·21
Cockle Park 1903	12·45	12·10	0·35	12·28	11·67	+0·61
Kelloe Hall 1902	11·87	12·27	0·40	12·07	12·14	−0·07
Grange Hill 1902	11·98	12·51	0·53	12·25	12·07	+0·18
Red Barns 1902	12·22	12·76	0·54	12·49	12·33	+0·16
Billingham 1902	13·00	13·40	0·40	13·20	13·15	+0·05
Average for North of England, all results						+0·20
,, ,, ,, ,, less highest						+0·12
,, ,, ,, ,, ,, lowest						+0·27
Dickson, Brown and Tait's Best of All.						
Cockle Park 1900	10·73	10·93	0·20	10·83	11·43	−0·60
Cockle Park 1901	9·28	9·99	0·71	9·63	10·32	−0·69
Cockle Park 1902	12·11	12·16	0·05	12·13	11·93	+0·20
Cockle Park 1902	11·59	11·51	0·08	11·55	11·93	−0·38
Cockle Park 1903	11·80	11·96	0·16	11·88	11·67	+0·21
Eshott 1903	11·64	11·81	0·17	11·72	12·12	−0·50
Eshott 1903	12·06	11·32	0·74	11·69	12·12	−0·43
Average for Northumberland						−0·31

* See Tables III and VI, also pp. 96 and 98.

TABLE X. (*continued*).

Variety and Station where grown	Dry Matter °/₀ Duplicates		Difference between duplicates	Average	11·28 + s + f	Variety factor
Dickson, Brown and Tait's Best of All.	·			A	s	v
New Raby 1901	11·49	10·95	0·54	11·22	11·10	+0·12
Kelloe Hall 1902	12·12	12·00	0·12	12·06	12·14	−0·08
Neasham Grange ... 1902	11·60	11·00	0·60	11·30	12·10	−0·80
Red Barns 1902	12·10	12·44	0·34	12·27	12·33	−0·06
Cleatlam 1902	12·40	12·26	0·14	12·33	12·58	−0·25
Billingham 1902	13·23	12·62	0·61	12·92	13·15	−0·23
Denton Grange 1903	12·91	13·13	0·22	13·01	13·03	−0·02
Portrack Grange.... 1903	10·63	10·42	0·21	10·53	11·08	−0·55
New Raby... 1903	10·70	11·60	0·90	11·15	11·25	−0·10
Sherburn Colliery ... 1903	11·80	11·87	0·07	11·84	12·15	−0·31
Average for Durham						−0·23
,, North of England, all results..............						−0·26
,, ,, ,, ,, less highest						−0·28
,, ,, ,, ,, ,, lowest						−0·22
Drummond's Extra Improved.						
Cockle Park 1900	11·67	11·01	0·66	11·34	11·43	−0·09
New Raby......... 1901	10·41	10·91	0·50	10·66	11·10	−0·44
Cockle Park............ 1901	9·67	10·59	0·92	10·13	10·32	−0·19
New Raby.. 1902	12·82	12·36	0·46	12·59	12·85	−0·26
Eshott 1902	13·14	13·54	0·40	13·34	13·16	+0·18
Cockle Park............ 1903	12·40	12·50	0·10	12·45	11·67	+0·78
Cockle Park. 1904	15·62	15·98	0·36	15·80	14·96	+0 84
Average for North of England, all results.....						+0·12
,, ,, ,, ,, less highest						−0·00
,, ,, ,, ,, ,, lowest						+0·21
Drummond's Stirling Castle.						
Cockle Park 1900	11·31	11·42	0·09	11·37	11·43	−0·06
Cockle Park............ 1901	10·53	10·63	0·10	10·58	10·32	+0·26
Eshott 1902	13·03	13·57	0·54	13·30	13·16	+0·14
Cockle Park............ 1902	11·78	11·93	0·15	11·85	11·93	−0·08
Cockle Park............ 1903	11·75	11·97	0·22	11·86	11·67	+0·19
Portrack Grange.. ... 1902	11·68	11·88	0·20	11·78	11·48	+0·30
Grange Hill 1902	12·58	12·92	0·34	12·75	12·07	+0·68
New Raby............... 1902	12·90	12·57	0·33	12·73	12·85	−0·12
Average for North of England, all results..						+0·16
,, ,, ,, ,, less highest						+0·09
,, ,, ,, ,, ,, lowest						+0·20
Fell's Bronze Top.						
Cockle Park.........:.. 1900	12·57	12·19	0·38	12·38	11·43	+0·95
Cockle Park............ 1901	10·05	10·76	0·71	10·41	10·32	+0·09
Eshott 1902	13·87	14·31	0·44	14·09	13·16	+0·93
Cockle Park.. 1902	12·52	12·44	0·08	12·48	11·93	+0·55
Cockle Park............ 1903	12·96	13·03	0·07	13·00	11·67	+1·33
Eshott 1903	12·63	12·70	0·07	12·66	12·12	+0·54
Eshott 1903	12·51	12·81	0·30	12·66	12·12	+0·54
Cockle Park............ 1904	15·85	16·49	0·64	16·17	14·96	+1·21
Average for Northumberland						+0·77

See Tables III and VI, also pp. 96 and 98.

TABLE X. (*continued*).

Variety and Station where grown	Dry Matter °/o Duplicates		Difference between duplicates	Average	11·23 +s +f	Variety factor
Fell's Bronze Top.				A	s	v
Portrack Grange...... 1902	12·03	12·03	0·00	12·03	11·48	+0·55
Grange Hill 1902	12·83	13·55	0·72	13·19	12·07	+1·12
Denton Grange 1903	13·71	14·03	0·32	13·87	13·03	+0·84
Portrack Grange...... 1903	10·90	11·66	0·76	11·28	11·08	+0·20
Sherburn Colliery ... 1903	12·63	13·25	0·62	12·94	12·15	+0·79
Average for Durham						+0·70
,, North of England, all results						+0·74
,, ,, ,, ,, less highest						+0·71
,, ,, ,, ,, ,, lowest						+0·80
Fell's Halewood Bronze Top.						
Cockle Park..... 1900	12·08	11·56	0·52	11·83	11·43	+0·40
Cockle Park......... ... 1903	11·02	10·98	0·04	11·00	11·67	-0·67
Eshott 1903	12·03	12·03	0·00	12·03	12·12	-0·09
Sherburn Colliery ... 1903	12·09	12·13	0·04	12·11	12·15	-0·04
Eshott 1903	12·67	12·49	0·18	12·58	12·12	+0·46
Cockle Park.... 1904	14·45	15·35	0·90	14·90	14·96	-0·06
Average for North of England, all results						0·00
,, ,, ,, ,, less highest						-0·09
,, ,, ,, ,, ,, lowest						+0·13
Garton's Model Bronze Top.						
Cockle Park 1900	10·70	10·57	0·13	10 64	11·43	-0·79
Cockle Park......... .. 1901	9·16	9·76	0·60	9·46	10·32	-0·86
Cockle Park............ 1903	10·93	11·02	0 09	10·97	11·67	-0·70
Average for North of England						-0·78
Kent and Brydon's Darlington.						
New Raby............... 1901	11·41	10·63	0·78	11·02	11·10	-0·08
Portrack Grange... .. 1902	11·13	11·07	0·06	11·10	11·48	-0·38
Grange Hill 1902	11·44	11·53	0·09	11·48	12·07	-0·59
Cleatlam 1902	12·60	12·10	0·50	12·35	12·58	-0·23
New Raby.............. 1902	12·80	12·61	0·19	12·70	12·85	-0·15
Average for Durham						-0·29
Cockle Park............ 1901	10·41	9·94	0·47	10·18	10·32	-0·14
Eshott 1902	12·56	12·55	0·01	12·56	13·16	-0·60
Cockle Park 1902	11·76	11·99	0·23	11·87	11·93	-0·06
Cockle Park............ 1903	10·77	10·98	0·21	10·87	11·67	-0·80
Cockle Park 1904	14·90	15·28	0·38	15·09	14·96	+0·13
Average for Northumberland						-0·29
,, North of England, all results						-0·29
,, ,, ,, ,, less highest						-0·34
,, ,, ,, ,, ,, lowest						-0·23

See Tables III and VI, also pp. 96 and 98.

TABLE X. (*continued*).

Variety and Station where grown		Dry Matter % Duplicates		Difference between duplicates	Average	11·23 +s +f	Variety factor
Kent and Brydon's XL All.					*A*	*	*v*
Cockle Park	1900	10·55	10·39	0·16	10·47	11·43	−0·96
Cockle Park	1901	9·69	10·15	0·46	9·92	10·32	−0·40
Riffington	1902	12·46	11·62	0·84	12·04	12·91	−0·87
Cockle Park	1902	11·22	11·25	0·03	11·23	11·93	−0·70
Cockle Park	1902	11·62	11·53	0·09	11·58	11·93	−0·35
Cockle Park	1903	11·17	11·44	0·27	11·30	11·67	−0·37
Eshott	1903	11·53	11·30	0·23	11·41	12·12	−0·71
Eshott	1903	10·91	11·36	0·45	11·13	12·12	−0·99
Average for Northumberland							−0·67
New Raby	1901	9·96	10·93	0·97	10·44	11·10	−0·66
Neasham Grange	1902	11·72	11·82	0·10	11·77	12·10	−0·33
Sherburn Colliery	1902	12·30	12·06	0·24	12·18	11·99	+0·19
Cleatlam	1902	12·10	11·69	0·41	11·90	12·58	−0·68
New Raby	1902	12·50	12·22	0·28	12·36	12·85	−0·49
Denton Grange	1903	12·22	11·80	0·42	12·01	13·03	−1·02
Portrack Grange	1903	10·65	10·75	0·10	10·70	11·08	−0·38
New Raby	1903	10·52	10·86	0·34	10·69	11·25	−0·56
New Raby	1903	10·82	10·43	0·39	10·63	11·25	−0·62
Sherburn Colliery	1903	11·00	11·40	0·40	11·20	12·15	−0·95
Average for Durham							−0·55
" North of England, all results							−0·60
" " " " less highest							−0·65
" " " " " lowest							−0·58
Sutton's Crimson King.							
Cockle Park	1900	11·33	11·63	0·30	11·48	11·43	+0·05
Cockle Park	1901	10·59	10·34	0·25	10·47	10·32	+0·15
Riffington	1902	12·25	12·50	0·25	12·37	12·91	−0·54
Cockle Park	1902	11·61	11·52	0·09	11·57	11·93	−0·36
Cockle Park	1903	11·06	11·38	0·32	11·22	11·67	−0·45
Cockle Park	1904	14·61	13·89	0·72	14·25	14·96	−0·71
Neasham Grange	1902	11·60	11·68	0·08	11·64	12·10	−0·46
Sherburn Colliery	1902	11·22	11·68	0·46	11·45	11·99	−0·54
Grange Hill	1902	11·60	11·93	0·33	11·76	12·07	−0·31
Average for North of England, all results							−0·35
" " " " less highest							−0·41
" " " " " lowest							−0·31
Webb's New Arctic.							
Cockle Park	1900	11·62	11·92	0·30	11·77	11·43	+0·34
Cockle Park	1901	10·82	10·92	0·10	10·87	10·32	+0·57
Cockle Park	1902	12·32	12·46	0·14	12·39	11·93	+0·46
Cockle Park	1902	12·21	12·23	0·02	12·22	11·93	+0·29
Cockle Park	1903	11·14	11·15	0·01	11·14	11·67	−0·53
Eshott	1903	11·99	11·68	0·31	11·83	12·12	−0·29
Eshott	1903	12·13	12·38	0·25	12·25	12·12	+0·13
Cockle Park	1904	15·02	15·38	0·36	15·20	14·96	+0·24
Average for Northumberland							+0·15

See Tables III and VI, also pp. 96 and 98.

TABLE X. (*continued*).

Variety and Station where grown	Dry Matter °/o Duplicates		Difference between duplicates	Average	11·23 $+s$ $+f$	Variety factor
Webb's New Arctic.				*A*	*	*v*
Kelloe Hall 1902	12·57	12·67	0·10	12·62	12·14	+0·48
Grange Hill 1902	11·91	12·14	0·23	12·02	12·07	−0·05
Red Barns 1902	12·78	12·80	0·02	12·79	12·33	+0·46
Billingham 1902	13·65	13·60	0·05	13·62	13·15	+0·47
Denton Grange 1903	13·35	13·28	0·07	13·31	13·03	+0·28
Portrack Grange...... 1903	10·90	10·95	0·05	10·92	11·08	−0·16
Sherburn Colliery ... 1903	12·71	12·03	0·68	12·37	12·15	+0·22
Average for Durham......						+0·24
,, North of England, all results						+0·19
,, ,, ,, ,, less highest						+0·17
,, ,, ,, ,, ,, lowest						+0·25
Webb's Imperial.						
Cockle Park 1900	12·25	11·93	0·32	12·09	11·43	+0·66
Cockle Park 1903	11·58	11·99	0·41	11·78	11·67	+0·11
Eshott 1903	11·79	11·86	0·07	11·83	12·12	−0·29
Sherburn Colliery ... 1903	12·25	12·38	0·13	12·32	12·15	+0·17
Eshott 1903	12·75	12·75	0·00	12·75	12·12	+0·63
Average for North of England, all results						+0·26
,, ,, ,, ,, less highest						+0·16
,, ,, ,, ,, ,, lowest						+0·39

See Tables III and VI, also pp. 96 and 98.

TOWN STABLE MANURE: ITS CHEMICAL COMPOSITION AND THE CHANGES IT UNDERGOES ON KEEPING.

By BERNARD DYER, D.Sc., F.I.C.

THE use of town stable manure enters so largely into the economy of farms, and especially market-gardens, situated within fairly easy distance of London or other large cities, that it is somewhat curious that but little information has been published in this country as to its chemical composition. In fact, with the exception of a couple of analyses made by myself as long ago as 1889, which were published at the time in the *Mark Lane Express*, and subsequently reprinted in Aikman's book on "Manures and Manuring," I do not remember to have seen any analyses of London manure. The samples which were the subject of these analyses were collected from a very limited number of stables, some of which were littered with peat moss and others with straw, the object at the moment being to compare the manure produced with the two kinds of litter. I have more recently however made some fairly full analyses of two more representative samples of London manure, but before proceeding to give these it may be desirable to reprint in this place, for future reference, the old analyses just mentioned.

ANALYSES OF STABLE MANURE—1889.

	Manure made with Peat litter		Manure made with Straw litter	
Water		77·84		70·03
Organic matter, &c. (loss on ignition)		18·02		24·28
*Phosphoric Acid		0·37		0·48
Lime		0·33		0·70
Potash		1·02		0·59
Magnesia, Soda, and other undetermined constituents		1·08		1·30
Siliceous Matter		1·34		2·62
		100·00		100·00
*Equal to Tribasic Phosphate of Lime		0·80		1·04
Total Nitrogen—		0·88		0·62
Organic	0·37		0·52	
Ammoniacal and Nitric	0·51		0·10	
Equal to Ammonia		1·07		0·75

If these results are calculated to the dry state we get:

	Manure made with Peat litter	Manure made with Straw litter
Organic Matter, &c. (loss on ignition) ...	81·12	82·36
*Phosphoric Acid ...	1·69	1·38
Lime ...	1·50	2·26
Potash ...	4·50	2·09
Magnesia, Soda, and other undetermined constituents ...	5·20	3·86
Siliceous Matter ...	5·99	8·05
	100·00	100·00
*Equal to Tribasic Phosphate of Lime ...	3·69	3·01
Total Nitrogen—		
Organic ...	1·67 } 3·93	2·10 } 2·51
Ammoniacal and Nitric ...	2·26 }	0·41 }
Equal to Ammonia ...	4·80	3·05

The comparatively recent analyses which I have made were in both cases analyses of what may be taken as representative samples of fresh London manure, consisting of peat-made manure and straw-made manure mixed. One sample was drawn from a consignment delivered in Kent and one from a consignment delivered in the Midlands. In each case samples were taken from a great many parts of the delivery and thoroughly mixed together, a fair sample of the resulting mixture being submitted to analysis. The results were as follows:

ANALYSES OF REPRESENTATIVE SAMPLES OF FRESH LONDON STABLE MANURE (PEAT MANURE AND STRAW MANURE MIXED)—1903.

	No. 1	No. 2	Average
Moisture ...	76·09	61·98	69·04
Organic Matter, &c. (loss on ignition) ...	19·30	26·37	22·82
*Phosphoric Acid ...	0·33	0·45	0·39
Lime ...	0·55	1·28	0·92
Potash ...	0·45	0·58	0·51
Magnesia, Soda, Oxide of Iron, Sulphuric Acid, and other undetermined constituents	0·69	2·70	1·70
Siliceous Matter (mainly sand) ...	2·59	6·64	4·62
	100·00	100·00	100·00
*Equal to Tribasic Phosphate of Lime ...	0·72	0·98	0·85
Total Nitrogen—			
Soluble ...	0·08 } 0·54	0·08 } 0·70	0·08 } 0·62
Insoluble ...	0·46 }	0·62 }	0·54 }
Equal to Ammonia—			
Soluble ...	0·10 } 0·66	0·10 } 0·85	0·10 } 0·76
Insoluble ...	0·56 }	0·75 }	0·66 }

COMPOSITION OF ABOVE SAMPLES CALCULATED TO THE DRY STATE.

	No. 1	No. 2	Average
Organic Matter, &c. (loss on ignition) ...	80·70	69·36	75·03
*Phosphoric Acid...	1·38	1·17	1·27
Lime	2·29	3·38	2·84
Potash	1·90	1·54	1·72
Magnesia, Soda, Oxide of Iron, Sulphuric Acid, and other undetermined constituents	2·90	7·08	4·99
Siliceous Matter (mainly sand)	10·83	17·47	14·15
	100·00	100·00	100·00
*Equal to Tribasic Phosphate of Lime ...	3·01	2·55	2·78
Total Nitrogen—			
Soluble	0·36 } 2·27	0·21 } 1·84	0·28 } 2·05
Insoluble	1·91 }	1·63 }	1·77 }
Equal to Ammonia—			
Soluble	0·44 } 2·76	0·25 } 2·23	0·34 } 2·49
Insoluble	2·32 }	1·98 }	2·15 }

Sample No. 1 probably contains as much moisture as one would expect to find in stable manure which had not been intentionally watered to increase its weight; while sample No. 2 is somewhat drier than is often the case.

The analyses which now follow are analyses of samples of London stable manure taken in February from stocks which had been stored in heaps on a farm since the previous summer.

ANALYSES OF SAMPLES OF OLD LONDON MANURE AFTER STORING IN LARGE HEAPS IN OPEN FIELD FROM SUMMER TO SPRING.

	A	*B*	*C*
Moisture	53·83	61·88	52·89
Organic Matter, &c. (loss on ignition) . .	17·46	21·98	22·98
*Phosphoric Acid...	0·49	0·56	0·66
Lime	1·41	1·20	1·72
Potash	0·58	0·65	0·80
Magnesia, Soda, Oxide of Iron, Sulphuric Acid, and other undetermined constituents	3·35	2·16	3·38
Siliceous Matter (mainly sand)	22·88	11·57	17·57
	100·00	100·00	100·00
*Equal to Tribasic Phosphate of Lime ...	1·08	1·22	1·44
Total Nitrogen—			
Soluble	0·06 } 0·64	0·08 } 0·76	0·10 } 0·89
Insoluble	0·58 }	0·68 }	0·79 }
Equal to Ammonia—			
Soluble	0·08 } 0·78	0·10 } 0·92	0·12 } 1·08
Insoluble	0·70 }	0·82 }	0·96 }

COMPOSITION OF ABOVE SAMPLES CALCULATED TO THE DRY STATE.

	A	B	C
Organic Matter, &c. (loss on ignition) ...	37·81	57·66	48·78
*Phosphoric Acid...	1·07	1·47	1·40
Lime	3·05	3 16	3·66
Potash	1·25	1·70	1·70
Magnesia, Soda, Oxide of Iron, Sulphuric Acid, and other undetermined constituents	7·27	5·66	7·17
Siliceous Matter (mainly sand)	49·55	30·35	37·29
	100·00	100·00	100·00
*Equal to Tribasic Phosphate of Lime ..	2·34	3·21	3·06
Total Nitrogen—			
Soluble	0·13 } 1·39	0·21 } 2·00	0·21 } 1·89
Insoluble	1·26 }	1·79 }	1·68 }
Equal to Ammonia—			
Soluble	0·16 } 1·69	0·26 } 2·43	0·26 } 2·30
Insoluble	1·53 }	2·17 }	2·04 }

The samples obviously contain an unduly large quantity of sand. This, however, was not earth which had found its way into the dung from the fields in which the heaps were situated. The samples represented a very large mass of manure which had not been mixed with soil during the making of the heaps, and the sand was in each case found distributed throughout the mass. I concluded that a large proportion of road scrapings had probably been included in the manure. If this was not the case, sand or gravel must have been deliberately mixed with it. I calculated that the three batches of manure represented probably contained, in the original condition in which the manure was delivered, from 8 per cent. to 18 per cent. of sand. It is to be hoped, in the interests of those who purchase large quantities of London manure, that such extensive admixtures with sand are not frequent.

These observations as to sand are, however, subsidiary to the main interest of the analyses, which lies in the information to be derived from them as to the extent to which losses of fertilising matter have taken place during storage. As no analyses had been made of the actual manure before it was put into the heaps, the amount of such losses can only be arrived at by a process of inference. I have endeavoured to make an approximate computation of the nitrogenous losses by considering the ratio of phosphoric acid to residual soluble and insoluble nitrogen, and have accordingly calculated, in the case of the two average samples of fresh London manure, the ratio of phosphoric acid to total, soluble and insoluble nitrogen:

FRESH LONDON MANURE.

		No. 1	No. 2	Average
$\frac{\text{Phosphoric Acid}}{\text{Total Nitrogen}}$	=	$\frac{100}{164}$	$\frac{100}{157}$	$\frac{100}{161}$
$\frac{\text{Phosphoric Acid}}{\text{Soluble Nitrogen}}$	=	$\frac{100}{24}$	$\frac{100}{18}$	$\frac{100}{21}$
$\frac{\text{Phosphoric Acid}}{\text{Insoluble Nitrogen}}$	=	$\frac{100}{140}$	$\frac{100}{138}$	$\frac{100}{138}$

In the three samples of manure which had been kept from summer to spring in heaps we find the following ratios:

OLD LONDON MANURE.

		A	*B*	*C*
$\frac{\text{Phosphoric Acid}}{\text{Total Nitrogen}}$	=	$\frac{100}{131}$	$\frac{100}{136}$	$\frac{100}{135}$
$\frac{\text{Phosphoric Acid}}{\text{Soluble Nitrogen}}$	=	$\frac{100}{12}$	$\frac{100}{14}$	$\frac{100}{15}$
$\frac{\text{Phosphoric Acid}}{\text{Insoluble Nitrogen}}$	=	$\frac{100}{118}$	$\frac{100}{121}$	$\frac{100}{120}$

If it be assumed that the samples of old manure would have shown originally, in the fresh state, ratios similar to those found for the samples of fresh London manure the difference between the ratios will afford material for calculating the losses which have taken place by fermentation in the heap.

The average ratio of the two fresh samples being taken as a basis, the losses would be as follows:

	A	*B*	*C*
Loss of original Total Nitrogen	19 per cent. (or say, roughly, one-fifth)	15 per cent. (or say, roughly, one-sixth)	15 per cent. (or say, roughly, one-sixth)
Loss of original Soluble Nitrogen	42 per cent. (or say, roughly, two-fifths)	30 per cent. (or say, roughly, one-third)	27 per cent. (or say, roughly, one-fourth)
Loss of original Insoluble Nitrogen	15 per cent. (or say, roughly, one-sixth)	13 per cent. (or say, roughly, one-eighth)	14 per cent. (or say, roughly, one-eighth)

The 1889 analyses are not comparable in all their details with the more recent ones, but it may be observed that in the old analyses the ratios of phosphoric acid to total nitrogen were $\frac{100}{238}$ for the peat manure and $\frac{100}{129}$ for the straw manure, the mean of the ratios for the peat manure and the straw manure being $\frac{100}{184}$. This mean ratio does not differ very much from that shown by the much more representative samples analysed later.

It may be added that the ratio of total "organic matter" to phosphoric acid in the two samples of fresh dung is respectively 58 : 1 and 59 : 1. In the three samples of manure that had been rotted down in the heaps, the ratio of organic matter to phosphoric acid was respectively 35 : 1, 39 : 1, and 35 : 1. It would thus appear that roughly speaking something like 40 per cent. of the organic matter disappeared in the process of fermentation, but the estimate can only be an approximation, because the item "organic matter" includes any water of hydration that may have been associated with the road scrapings, etc. Possibly the loss of actual organic matter may have been even greater.

London stable manure owes no small part of its practical value to the organic matter contained in it. The useful functions of this organic matter—whether for light or for heavy soils—need not be enlarged upon here; but since so large a diminution of the organic matter occurs in the heap it would seem to be good policy, quite apart from the question of loss of nitrogen, to apply the manure to the soil in as fresh a state as may be consistent with convenience and good farming.

SOIL ANALYSIS AS A GUIDE TO THE MANURIAL TREATMENT OF POOR PASTURES.

By T. B. WOOD, M.A., *Reader in Agricultural Chemistry*,

AND R. A BERRY, F.I.C., *Assistant Chemist, Agricultural Department, Cambridge University.*

During the last five years the Cambridge University Department of Agriculture has been associated with H. M. Board of Agriculture, and with the County Councils of Cambridge, Essex, Norfolk, and Northampton, in carrying out a number of experiments on the improvement of poor pastures. The improvement has been measured by the increase in live-weight of sheep grazing the variously treated plots, and the results have in many cases been so good that an examination of all the soils has been made in order if possible to classify them, so that definite information might be available as to the kind of soil on which poor pastures might be capable of improvement by manuring.

Accordingly, samples of soil have been obtained from each station, and in many cases from each plot, and analysed chemically and mechanically, and in the following pages an attempt is made to collate the results of the field experiments with the analytical figures in order to see how far examination of a soil in the laboratory may indicate the best treatment to adopt.

The experiments, of which the agricultural results are given in Middleton's paper on *The Improvement of Poor Pastures* (see pp. 122—145), were carried out at the following stations:

Cransley—Northants. Boulder clay soil.
Hatley—Cambridge. Boulder clay soil.
Yeldham—Essex. Boulder clay soil.
Trowse—Norfolk Sandy soil.

In addition to these four stations we are able to give the figures for two others:

Cockle Park—Northumberland. Boulder clay soil.
Sevington—Hampshire. Sticky soil on chalk.

The figures for Cockle Park are taken from Somerville's "Five years' work at the Northumberland County Farm," and from the Annual Reports of the Durham College of Science; those for Sevington from the *Journal* of the Bath and West of England Society, 1903–4.

The analyses, except some of those for Cockle Park and some for Yeldham, are our own. The Cockle Park analyses are acknowledged above. For those of Yeldham we are indebted to Mr T. S. Dymond, F.I.C., of the Essex County laboratories, Chelmsford.

In our own work we have adopted for the chemical analysis the method agreed upon by the Agricultural Education Association, and described by A. D. Hall[1]; and for the mechanical analyses the method described also by Hall[2].

In the following tables the figures indicating the result of the various manures are calculated as follows:—The live-weight increases on each plot are averaged for the first three years after the application of the manures, except at Trowse, where the experiment could only be continued for two years. The average live-weight increase on the unmanured plot is then taken as 100, and the increase produced by each manure is calculated as a percentage of the increase on the unmanured plot.

Absolute increases are of course greater in good, than in bad seasons, but percentage increases do not vary nearly so much, as a good season increases the produce on both unmanured and manured plots. Percentage live-weight increase calculated thus, and averaged for three years, should give a reliable basis of comparison.

PHOSPHATES.

The most notable result of the experiments from the agricultural point of view is the very great improvement in the feeding value of the pasture produced by the application of a large dressing of basic slag. In the following table the figures showing this improvement, as average percentage live-weight increase, are set out side by side with the percentages of total and citric acid soluble phosphoric acid in the soils.

[1] *The Analyst*, November, 1900.
[2] *J. Chem. Soc.* 1904, 950.

	Yeldham	Cockle Park	Hatley	Cransley	Sevington	Trowse
Average % live-wt. increase due to ½ ton basic slag*	240	233	127	106	38	-2
Percentage in soil of phosphoric acid (P_2O_5) sol. in strong hydrochloric acid	0·15	0·07	0·33	0·12	0·18	0·18
Percentage in soil of phosphoric acid (P_2O_5) sol in 1 % citric acid	0·011	0·005	0·014	0·013	0·013	0·041

* Containing 200 lbs phosphoric acid.

It is evident at once that only one of the soils can be called deficient in total phosphoric acid, namely Cockle Park, and only one soil, Hatley, exceptionally rich in that substance. A determination of the total phosphoric acid in the soil at Cockle Park indicates that no treatment could really improve the pasture which did not include the application of phosphatic manure. At Hatley, however, the percentage of total phosphoric acid clearly indicates that phosphate is not required, and the indication is entirely wrong, for basic slag has given a very profitable improvement. No clear indication can be drawn from the analytical figures for total phosphoric acid at the other stations. Determination of the total phosphoric acid gives a correct indication at Cockle Park, an incorrect one at Hatley, and fails to indicate one way or other at the other four stations.

A determination of the citric acid soluble phosphoric acid gives better results, for it again suggests the right treatment for Cockle Park, and shows that phosphate is not needed at Trowse. The percentages at the other four stations are just above Dyer's limit of 0·01 per cent.[1], and therefore suggest that phosphatic manuring is hardly needed. In three of the four cases, however, basic slag has made a great improvement, and quite a distinct one at the fourth station. For pasture soils, therefore, it appears as Hall suggests[2] that this limit of 0·01 per cent. needs revising. Enough information is not to hand at present, but the above figures appear to suggest that phosphates may be expected to give distinct results on pasture soils containing less than 0·02 per cent. phosphoric acid soluble in 1 per cent. citric acid, provided of course that other conditions are suitable for the phosphates to act. The necessity for raising the limit for citric acid soluble phosphoric acid in pasture soils is probably that citric acid dissolves organic matter, including organic phosphorus, if the soil is rich in humus. Probably the limit for

[1] *J. Chem. Soc.* 1894, 115, and *Phil. Trans.* 1901, 235.
[2] *J. Chem. Soc.* 1902, 117.

peaty soils should be higher still, for peats from the Isle of Ely, which respond very profitably to phosphatic manuring, yield as much as 0·05 per cent. phosphoric acid to 1 per cent. citric acid solution[1].

The analytical figures even for the citric acid soluble phosphoric acid do not come in the order indicated by the results with the sheep, but this can hardly be expected when we consider the indirect manner in which basic slag acts on the mixed herbage of a pasture, as shown by Middleton. (See p. 134.)

LIME AND CHALK.

The percentage of lime in a soil, and especially perhaps the percentage of calcium carbonate, may be expected to indicate, (1) if the soil needs liming, (2) whether basic slag or superphosphate may be expected to give the better result

The figures bearing on these points are given in the following table. The amounts of basic slag and superphosphate each supplied 100 lbs. phosphoric acid per acre.

	Yeldham	Cockle Park	Hatley	Cransley	Sevington	Trowse
Average % live-wt. increase due to 4 tons lime	—	4	—	26	3	—
Average % live-wt increase due to 5 cwt. basic slag	106	96	95	53	24	-2
Average % live-wt. increase due to 7 cwt. super.	62	91	85	47	30	-14
Percentage CaO in the soil	1·64	0·69	1·15	0·63	2·87	1·36
Percentage $CaCO_3$ in the soil	1·30	0·59	0·91	0·27	4·20	1·90

As regards liming, analysis indicates only the Cransley soil as deficient in lime, and especially in calcium carbonate, and the indication is valuable, for it is only at Cransley that liming has given any appreciable effect. The effect is, however, still too small to be profitable, and the limit for calcium carbonate below which liming may be expected to be profitable is therefore probably below 0·25 per cent. Leaving out Trowse, for reasons which will be pointed out later, basic slag has given a better return than superphosphate at all the stations except Sevington, where the percentage of chalk is very high, 4·20 per

[1] *Annual Report, Cambridge and Counties Agricultural Education Scheme*, 1898.

cent. This appears to indicate that basic slag is a more suitable manure than superphosphate for poor pastures, unless there is a very high percentage of chalk in the soil.

Potash.

In the following table are given the results of potash manuring, and the percentages of potash in the soils. The former are calculated by subtracting from the live-weight increases produced by potash applied with phosphate that produced by the same quantity of phosphate applied alone.

	Yeldham	Cockle Park	Hatley	Cransley	Sevington	Trowse
Average % live-wt. increase due to potash	—	27	—	43	-7	20
Percentage in soil of K_2O soluble in HCl	0·52	0·50	0·80	0·57	0·55	0·13
Percentage in soil of K_2O soluble in citric acid 1 %	0·010	0·013	0·009	0·008	0·008	0·007

The figures for potash soluble in hydrochloric acid show exactly what might be expected—plenty of "total" potash in all the heavy soils, and a deficiency in the sandy soil of Trowse.

The figures for citric soluble potash are all low, the highest, Cockle Park, being only very slightly above the limit at which potash manuring may be expected to give distinct results[1]. The live-weight increases agree very well with the analytical figures for potash soluble in citric acid. At three of the four stations where potash was applied it has given a distinct increase. At Sevington the failure of potash is probably due to the fact that the land produced too much coarse grass in the first year of the experiment, and the sheep were consequently unable to eat it down. (See p. 130.)

Nitrogen.

Some of the plots received ammonium sulphate or sodium nitrate in addition to phosphates, and although nitrogenous manures cannot be expected to give good results on pastures when used in this way, it may be worth while to give the figures.

[1] Dyer, *Phil. Trans.* 1901, 235.

	Yeldham	Cockle Park	Hatley	Cransley	Sevington	Trowse
Average °/₀ live-wt. increase due to Nitrogen .	28	14	—	33	-15	0
Percentage of Nitrogen in soil	0·19	0·20	0·25	0·30	0·21	0·13

The figures show that a determination of nitrogen in a pasture soil gives no indication as to the effect of nitrogenous manuring. The effect of nitrogen has nowhere been great, and on inspecting the plots one reason is seen to be that it produces increased growth of grasses, interfering with the spread of clovers which the phosphates ought to produce in order that the pasture may be improved. (See p. 139.)

MECHANICAL ANALYSES.

Mechanical analyses have been made of all the soils, and the results are given in the following table side by side with the percentage live-weight increase produced by 10 cwt. basic slag.

	Yeldham	Cockle Park	Hatley	Cransley	Sevington	Trowse
Percentage in soil—						
Water	3·2	1·8	3·5	4·5	2·7	1·2
Organic matter	6·0	9·7	9·7	11 0	7·9	5·0
Stones - diameter over 3 mm.	—	0 6	3 0	2·1	11·8	10·7
Particles						
diameter 3 mm.—1 mm.	0	-	1·2	1 0	1·0	2·7
,, 1 ,, — ·2 ,,	26·3	23·3	20·5	7 4	5·9	60 0
,, ·2 ,, — ·04 ,,	23·9	25·2	13 0	15·0	16·1	11·0
,, ·04 ,, — ·01 ,,	11·5	10·6	11·1	11·5	18·8	3·6
,, ·01 ,, — ·004 ,,	7·2	9·6	7·8	9·8	7·1	0·7
,, ·004 ,, — ·002 ,,	1·4	2·3	9·5	6 1	6·4	0·7
,, ·002 ,, and under .	15·0	11·9	18·7	25·8	18·2	0·3
Percentage live-wt. increase due to ½ ton basic slag . . .	240	233	127	106	88	-2

Inspection of the above table shows that the Trowse soil stands apart from all the others. It contains 60 per cent. of sand and only traces of the finer particles, and is of such coarse texture that it is unable, except when the summer rainfall is very great, to supply the herbage with enough water. Under these conditions the crop is limited

rather by the supply of water than by the amount of available plant food, and manurial treatment is therefore without effect. This is confirmed by the difference in the live-weight increase of the sheep on the cake-fed plot in 1901 and 1902. In the former year when the rainfall in May and June was about 2 inches, the sheep only gained 108 lbs., whilst in 1902 with 6 inches rainfall in the same period the sheep gained over three times as much. On such land, where rainfall is the predominant factor in determining the crop, manurial treatment for pastures must be comparatively ineffective.

Of the other soils, Cockle Park and Yeldham, which contain distinctly more sand and less clay, and approximate most nearly to a mixed soil, have reacted best to manuring, but this may in the former be due to its deficiency in phosphate. Still Cransley and Sevington with very little sand and much more clay have not reacted so well to manuring, and Hatley is intermediate both in content of sand and clay, and in reaction to basic slag.

It would appear therefore that while manures fail to improve pasture on very sandy soils owing to deficient water supply, a certain amount of sandy particles must be present in the soil to prevent the surface from baking hard and cracking.

Summary.

Summarising the above comparisons between soil analyses and results of manuring, the following conclusions are arrived at:

That except in extreme cases the determination of the percentages of "total" nitrogen, phosphoric acid, potash, and lime, in a soil does not give reliable indications as to the possibility of improving the pasture by manuring.

That determination of the percentage of phosphoric acid soluble in 1 per cent citric acid solution does generally give reliable indications as to the probable success of phosphatic manuring, provided that for pasture soils the limit below which "available" phosphoric acid may be considered as deficient is fixed as high as 0·02 per cent.

That potash manuring is suggested as likely to give distinct results if the soil contains not more than 0·01 per cent. of potash soluble in 1 per cent. citric acid solution.

That liming is not indicated as likely to be profitable unless the soil contains certainly less than 0·25 per cent. of chalk.

That basic slag is nearly always a better source of phosphoric acid for pastures than superphosphate, unless perhaps when the soil contains an exceptionally high percentage of chalk

That pastures are not likely to be improved by manuring unless their soil contains fair proportions of both large and small particles, and that the effect of manures is greater the more regularly the various grades of different sized particles are represented in the constitution of the soil

Determinations of citric acid soluble phosphoric acid and potash, and of calcium carbonate, and mechanical analysis of the soil, together with careful observations of the herbage which the land in its unmanured condition is producing, may be expected to indicate clearly those soils which are likely to be improved for pasturage by manuring with phosphates and potash.

THE IMPROVEMENT OF POOR PASTURES.

By T. H. MIDDLETON, M.A.,

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During the second half of the 19th century it is probable that between four and five million acres of the poorest arable land of England reverted from corn-growing to grass Since 1872 the increase in grass land has been over three million acres, and during the earlier period, for which statistics are not available, the fluctuating prices of wheat after 1850 must have been responsible for both the breaking up and laying down to grass of considerable areas of poor corn land[1].

A large proportion of the land laid down to grass since 1850 now forms grazing of the worst description. The surface has not become properly covered with vegetation, there is nothing that approaches a close turf, and the land bears no resemblance to what the farmer understands by the term old pasture. Within the past ten or fifteen years some of these poor grazing grounds have been improved by the use of basic slag and other manures, but one has only to study the *Agricultural Returns* to be convinced of the utterly unproductive state of most of the land converted into permanent pasture during the past half-century. This class of grass land is usually let at from 2*s*. 6*d*. to 7*s* 6*d*. per acre, and the reluctance of owner or occupier to expend capital on such unremunerative property is not surprising. A mistake in dealing with these pastures is likely to be a costly mistake, and they are therefore left alone. But there is no real reason for thus neglecting them; no class of land responds with such certainty to proper treatment, and if landowners only realized the "inherent capabilities" locked up in these apparently barren soils, if they knew how easily the stores might be

[1] The average price of wheat in the United Kingdom for the years 1850–52 was 39*s*. 10*d*., for 1854–56, 72*s*. 1*d*., for 1863–65, 42*s*. 3*d*. See Blue-Book on British and Foreign Trade, 1903 [Cd. 1761], p. 121.

unlocked, if they understood the uses of the "key," two million acres of the most neglected and unproductive land in England could be turned into pastures of fair quality.

The principles underlying the proper treatment of poor pastures resting on clay or clay-loam soils have been demonstrated by the results of a series of six experiments conducted in different parts of England. These experiments are all of the same type and were designed by Dr Somerville. The first was laid down on Cockle Park, the experimental farm of the Northumberland County Council, in the winter of 1896–97, and the others were started in 1900 or 1901. Two of the later experiments were exact reproductions of the original at Cockle Park, and were arranged by H.M. Board of Agriculture; these were the experiments at Cransley, Northamptonshire, which is supervised by the Cambridge University Department of Agriculture for the Board of Agriculture and the County Council, and the experiment at Sevington, Hampshire, undertaken by the Bath and West of England Society. The management of the Hampshire experiment is in the hands of Mr Ashcroft, the Society's steward of experiments, and the analytical work has been done at Cambridge. The three remaining experiments are on a less extensive scale. They are supervised by the Cambridge University Department of Agriculture, and were laid out at East Hatley, Cambridgeshire; at Yeldham, Essex, in conjunction with the Agricultural Education Sub-Committee of the County Council; and at Trowse, Norfolk, in association with the Norfolk Chamber of Agriculture Reports on these experiments have been published[1], but the collective results have not been discussed. In this paper a *résumé* of the results is given and the principles governing the rational treatment of poor pastures are explained.

In all the pasture experiments a suitable field of poor quality was selected and the land was then divided up into plots of $3\frac{1}{20}$ acres. Each plot was suitably fenced and was treated with the manures shown in Table I. The results of the manurial treatment have been ascertained by pasturing sheep on the plots for from 16 to 20 weeks in each season. Carefully selected sheep are weighed at the beginning of the

[1] See Annual Reports on Experiments Nos. VI, VII, VIII, and IX, issued by the Agricultural Depart. of the Durham College of Science; Somerville's "Five years' work at the Northumberland County Farm"; Reports on Cockle Park Experimental Farm, Nos. VI and VII, published by the Northumberland County Educ. Committee; Annual Reports on Experiments Nos. III, IV, and V, and Report on the Cransley Experiment, issued by Cambridge Univ. Agric. Dept.; Report on the Sevington Experiment, *Journal* of the Bath and West of England Society, 1903–04.

season, and also at the end of each month throughout the season, the total increase in live-weight is thus ascertained. The increase made shows the effects of the manures on the pastures. Sheep are kept in reserve in case of accidents to those grazing the plots, and precautions are taken to ensure that the records are not vitiated by the occurrence of illness in any of the animals.

A sub-plot of $\frac{1}{20}$th acre is fenced off before the sheep are put on the pastures and is cut for hay. A different plot is enclosed in each season, so that the grass cut may be a sample of the grass fed to sheep.

The Experimental Pastures.

Chemical and mechanical analyses of the soils have been made, and these are discussed in a paper by Wood and Berry (see pp. 114—121). A number of botanical analyses of the herbage have also been made. The most complete series is in connection with the experiment at Cockle Park, and references and figures will be found in the reports already cited.

It is outside the scope of the present paper to discuss the results of the botanical analyses, but before presenting the agricultural results an attempt will be made to indicate the general character of the herbage found on the different experimental pastures.

Cockle Park. A wretched pasture, laid down 30 or 40 years ago, and now worth from 2*s.* 6*d.* to 5*s.* per acre. The herbage at the time the experiment began consisted chiefly of bent-grass (*Agrostis* sp.) and heath-grass (*Triodia procumbens*) Associated with these in much smaller quantities were Yorkshire fog (*Holcus lanatus*), crested dogstail (*Cynosurus cristatus*), golden oat-grass (*Avena flavescens*), and cocksfoot (*Dactylis glomerata*). Irregularly scattered over the surface were patches of bird's-foot-trefoil (*Lotus corniculatus*) and medick (*Medicago lupulina*), and everywhere,—though so small as scarcely to enter into the edible herbage,—minute plants of white clover (*Trifolium repens*). The soil of the unmanured plot is nowhere closely covered, and though usually overspread by a coarse mat of dead bent, the surface soil is always visible. The bleached brown colour of the winter covering persists into June, when the fresh growth of bent gives a dull green tint to the surface; in August the purple panicles of bent distinguish the untreated plot from its neighbours, and a few weeks later the yellow tints of culm and blade give to the pasture a dull yellow-brown, very characteristic appearance. There is usually no lack of herbage on

the unmanured plot at Cockle Park, but it is so coarse in quality as to have little or no value for stock.

East Hatley. This field, which has been in grass for from 15 to 20 years, is not quite so poor as the last, but as the climate is less favourable than in the North of England, its value for grazing purposes is about the same. There is a good deal less white clover and more of the other Leguminosæ than at Cockle Park, and in some seasons bird's-foot-trefoil is very abundant. The grasses are well represented, and while bent predominates, crested dogstail, Yorkshire fog, meadow grasses (*Poa* sp.), timothy (*Phleum pratense*), and cocksfoot are fairly common. The soil is much more closely covered by vegetation than at Cockle Park, and the prominent defects of the pasture are that the herbage is late in growing, and that when it does begin to grow it rapidly becomes very coarse.

Yeldham. This field had been laid down to grass about 12 years when the experiment began. As sheep pasture it is perhaps the worst of the series. Medick is the predominant leguminous plant, and though white clover is common, the great increase produced by manures is due to the development of the former rather than of the latter. There is relatively little *Agrostis*, rye-grass (*Lolium perenne*) is common, but the characteristic grass on the unmanured land is crested dogstail. This grass developes few leaves, the hard culms soon shoot up, and the undergrowth dies, so that after the middle of July there is very little food for sheep. The soil, being unoccupied by grasses and clovers, is taken possession of by weeds. Cat's-ear (*Hypochœris*) and plantain (*Plantago*) are especially numerous.

Cransley. This pasture was laid down 20 to 30 years ago and is worth 4*s*. to 5*s*. per acre. The herbage is of the same type as at Yeldham, but the grasses do not seed so readily, and while, in August, the unmanured plot at Yeldham is covered by whitened dogstail culms, the corresponding Cransley plot is bare and closely grazed. Medick and suckling clover (*Trifolium minus*) are very common, white clover, though common, is much less abundant than at Cockle Park. While the Yeldham pasture contains a good deal of *Agrostis*, there is very little here. Among the grasses dogstail predominates, red fescue (*Festuca rubra*) is very abundant on the moister portions of the field and other small fescues are common all over the plots. Rye-grass and Yorkshire fog are also represented. A great deal of the surface is occupied by daisies (*Bellis*) and by hawkweeds (*Hieracium*).

Sevington. This pasture was laid down about 1892, and is worth

7*s*. to 10*s*. per acre. Ashcroft describes the herbage as even in character, "the plots varying more internally than one from another, except that Plots 9 and 10 have stronger tendency to a vigorous growth of top grass[1]." Both the chemical analysis, however, and the botanical separation of the herbage of 1901 indicate considerable variations from plot to plot, and these differences have somewhat affected the results. The pasture is of fair quality, and much better than those already described; medick is the chief leguminous plant, but white clover is common. Cocksfoot predominates among the grasses, and rye-grass, dogstail, and soft brome (*Bromus mollis*) are all abundant.

The botanical analysis of 1901 revealed a very unequal distribution of cocksfoot and medick over the plots. The figures were

	Dactylis	*Medicago*
Plots 1— 5	3—12 p c.	35—49 p.c.
„ 7—10	59—69 „	10—13 „

The actual differences in the grazing qualities are much less than these figures suggest, a preliminary experiment made with sheep in 1900 showed on Plots 1—5, 70 lbs increase per acre, and on Plots 7—10, 73 lbs. But under the influence of manures the natural differences have been accentuated, and when the writer visited the field in June, 1903, it was evident that the quantity of cocksfoot in the herbage of one side of the field, and especially in Plots 8—10, was injuriously affecting the quality of the pasturage

Trowse. The five pastures described above all occupy clay or strong loam soils, at Trowse the soil is sandy, and as on all sandy soils the herbage varies greatly with the season. In 1902 the field was covered with dry, leafless brome-grass (*Bromus mollis*): very few other grasses were to be seen. The undergrowth was very poor, and with the exception of suckling clover, which was plentiful in parts of the field, the clovers were badly represented. The general appearance of the field in the middle of June was that of a meadow rather than that of a pasture.

We have then in the six poor pastures selected for experiment, types of herbage of a somewhat different character. Cockle Park represents those pastures in which bent-grass predominates among Gramineæ, and white clover among Leguminosæ. Cransley is typical of the numerous poor pastures occupied by such grasses as crested dogstail and the smaller fescues, and such leguminous plants as medick and

[1] Bath and West of England Society's *Journal*, 1903–04, p. 158.

suckling clover. At Sevington, associated with the same leguminous plants we have the stronger grasses, cocksfoot and rye-grass.

The Hatley and Yeldham pastures are intermediate types. The former between Cockle Park and Cransley, the latter between Cransley and Sevington.

At Yeldham, as at Cransley, crested dogstail and medick are the predominant plants. After manuring rye-grass and cocksfoot develop strongly and, as at Sevington, the grasses readily run to seed. Yeldham grows a good deal more bent-grass than Cransley, and in this respect is intermediate between Cransley and Hatley.

The pasture at Trowse stands quite by itself, and as the results at this station differ markedly from those obtained on the clay soils, consideration of them will be deferred until the results from the five remaining experimental pastures have been discussed.

MANURES AND RESULTS FOR THREE SEASONS.

The manurial treatment of each of the plots, together with the increase for the first three years, *in excess of the increase on untreated land* will be found in Table I. Before we attempt to draw conclusions from those figures, however, there are certain points to which attention must be directed.

The figures in the case of Plot 1 relate to a single year. During the first two seasons the sheep on this plot received oilcake. Feeding with oilcake was stopped in the third year, so that the effects of the residues might be tested. The results of the third season's grazing of this plot, which have been given in Table I, show that the residues have produced an appreciable increase on all the clay soils, and a marked effect at Cockle Park[1]. The influence of these residues on the pastures, however, was not favourable, some of the grasses were encouraged, but the improvement was temporary, and the change in the character of the herbage was not of a satisfactory kind.

Quicklime produced a small increase at Cransley on a soil very deficient in lime, but at Cockle Park and Sevington it was practically without effect.

Plots 3, 4, and 5 were treated respectively with 200 lbs. phosphoric

[1] There is reason to suspect, however, that this increase has been slightly exaggerated. Plot 1 occupies the part of the field nearest the homestead and, through stock lying upon it, was somewhat better than Plot 6 when the experiment was begun.

TABLE I. Pasture Experiments at Six Stations. Results of third season on Plot 1. On the other Plots the average results are given for the first three seasons (at Trowse for two seasons only). Results stated in terms of the Live-Weight Increase of Sheep *in excess of the Increase on the Unmanured Plot.* Grazing Plots 3 acres. Figures "per acre."

Plot	TREATMENT	Cockle Park, Northumberland	Cransley, Northamptonshire	Sevington, Hampshire	Hatley, Cambridgeshire	Yeldham, Essex	Trowse, Norfolk	Average of Cockle Park, Cransley and Sevington	Average of all stations except Trowse	Approximate Cost of Manures per Acre in terms of Increase	Annual Live-Weight Increase or Decrease at Cockle Park, Cransley, and Sevington, deducting cost of Manures
		lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.
1	Residue of Linseed or Cotton Cake fed in first two seasons	58	16	31	16	14	—	35	27	?	—
2	4 tons Quicklime in first season	2	14	4	—	—	—	7	—	64	−57
3	200 lbs. Phosphoric acid (P_2O_5) in about 10 cwt. Basic Slag in first season	107	56	44	85	68	−5	69	72	28	41
4	100 lbs. Phosphoric acid in about 5 cwt. Basic Slag in first season	44	28	28	64	30	—	33	39	14	19
5	100 lbs. Phosphoric acid in about 7 cwt. Superphosphate in first season	42	25	35	57	18	−22	34	35	19	15
7	Super. as for Plot 5 with 50 lbs. Potash (K_2O) in Sul. of Potash or Kainit in first and third seasons	54	47	27	—	—	9	43	—	36	7
8	Super. as for Plot 5 with about 10 cwt. ground Quicklime in first and third seasons	55	49	27	—	—	—	44	—	43	1
9	Super. as for Plot 5 with 14 lbs. Nitrogen in Sulphate of Ammonia in first and third seasons	48	42	17	—	26	—	36	—	35	1
10	100 lbs. Phosphoric acid and 14 lbs. Nitrogen in Dissolved Bones in first season	48	44	19	—	—	—	37	—	33	4

Notes. The average increase for the first three years on the unmanured plots was as follows:—Cockle Park 46 lbs., Cransley 53 lbs., Sevington 115 lbs., Hatley 67 lbs., Yeldham 30 lbs., Trowse 156 lbs. per acre.

The manures were applied in winter or early spring. The cost of the manures has been expressed in lbs. increase, and the net increase has been entered in the last column on the assumptions that live increase is worth 35*s.* per cwt., and that the entire cost of the manures is paid for in three years.

In the first two years the quantities of cake fed on Plot 1 were, per acre: Cockle Park and Sevington 5¼ cwt., and Cransley 6¾ cwt. Decorticated Cotton Cake; Hatley 5 cwt., and Yeldham 9½ cwt. Linseed Cake; Trowse 7½ cwt. mixed Linseed and Undecorticated Cotton Cake.

Plots 5 and 7 at Trowse received 200 lbs. Phosphoric Acid in Superphosphate.

Plot 9 at Yeldham received 20 lbs. Nitrogen in 1901 and 1902, and 40 lbs. in 1903.

acid per acre in basic slag, 100 lbs. in basic slag, and 100 lbs. in superphosphate. Although the influence of phosphatic manure is not usually marked until the second year, the average increase of the three seasons has been so great that the cost of the manures has been recovered two or three times over. At every station the larger of the two dressings of slag was most profitable, and at three out of five stations Plot 3 produced twice, or more than twice, the increase produced on Plot 4. This reversal of the law of "diminishing returns" is not accidental, and it indicates that the effect of the manure is not of the usual kind, but has to some extent been indirect. As a source of phosphates the cheaper and insoluble basic slag has equalled or surpassed superphosphate, except on the calcareous clay soil of Sevington.

At Yeldham the poor returns from superphosphate are probably accidental. The difference between Plots 4 and 5 was due to the results obtained in season 1902. In that year Plot 4 grew a much heavier crop of medick than Plot 5. In other respects the plots were similar. There is no reason to suppose that medick is more encouraged by basic slag than by superphosphate, for at Sevington, where medick is, as at Yeldham, the leading representative of the Leguminosæ, Plot 5 excelled Plot 4. Medick appears to be very easily affected by slight changes in soil and environment, and its distribution over a pasture is often irregular. In the case of Yeldham it is likely that this irregularity has caused the difference in the effects of basic slag and superphosphate[1].

At Cockle Park and also at Cransley the addition to superphosphate of a potash manure on Plot 7, of lime on Plot 8, and of nitrogenous manures on Plots 9 and 10, has increased the yield, while at Sevington there has been a decrease in every case. The figures for Plots 7 to 10 at the Northampton and Hampshire stations require explanation. A preliminary feeding experiment at both stations showed that in season 1900 the quality of the pastures was practically the same. The results of the preliminary test at Sevington have already been given (see p. 126) At Cransley the sheep on Plots 1–5 increased 54 lbs. per acre, while those on Plots 6—10 increased 51 lbs. But although the preliminary tests were satisfactory the fields prove not to be so uniform as at first appeared to be the case.

The two groups of plots at Cransley occupy different sides of a field, and the second group, from the slope of the surface is a little drier than

[1] A change in the slope of the field probably accounts for the irregular distribution of medick. The soil itself appears to be uniform.

the first. During the wet summers of 1902 and 1903 Plots 7 to 10 had a distinct advantage over Plot 5, and as the result of repeated inspections of the experiment in these seasons the writer has come to the conclusion that the effects attributed by the figures in Table I to the action of potash, lime, and ammonia at Cransley, are exaggerated by from 10 to 15 lbs.

At Sevington the quality of the herbage as sheep pasture appears gradually to deteriorate from Plots 5 to 10, and it is unlikely that the use of potash and lime has depressed the yield to the extent indicated in Table I. The deficits in Plots 7 and 8 as compared with Plot 5 are chiefly due to the poor results obtained from the potash and lime plots in 1901. In 1902 and 1903 the results from Plots 5, 7, and 8 were nearly the same (they averaged 169 lbs., 168 lbs., and 164 lbs. per acre increase respectively), and it is clear that the difference in 1901 was due more to the composition of the herbage (see p. 126) than to the manures.

With respect to Plots 9 and 10 it appears probable that nitrogenous manures have been directly injurious at Sevington (by causing the grasses to run to stem).

In the case of Cockle Park there have been no disturbing factors, and as in the writer's opinion the results from Plots 7–10 at Sevington are too low by about the same amount that those of Cransley are too high (10–15 lbs. per acre), the figures in the average column in Table I appear to him to represent the actual effects of the manures used on Plots 7–10.

With these explanations the following conclusions may be drawn from the figures given in Table I. The conclusions apply to pastures on clay soils in an impoverished state, and they cover a period of three years from the time that the work of improvement has been begun.

1. Phosphatic manures produce a highly profitable increase. A 10 cwt. dressing of basic slag is more profitable than a 5 cwt. dressing, and basic slag surpasses superphosphate. (Two of these conclusions apply not only to the average results but to every one of five stations situated in five counties representing the North, Midlands, East, and South of England The third conclusion applies to four stations only; on the calcareous clay soil of Sevington superphosphate has been slightly more profitable than basic slag.)

2. Potash manures have been used at three stations in conjunction with superphosphate, and in two cases have considerably increased the yield. In one of these cases the increase has apparently left a profit, but reasons exist for thinking the profit doubtful, and on the whole evidence

it may be concluded that potash manures are seldom likely to be of importance on clay soils during the earlier stages of improvement.

3. The remarks made with respect to potash apply also to lime so far as the results stated in Table I are concerned, but further evidence exists, and will be given below, showing that lime has an important effect when used with superphosphate.

4. Nitrogenous manures have had a slight effect in increasing the pasturage, but they interfere with the action of phosphates, and their use during the early stages of improvement is to be strongly condemned.

5. In the absence of other manures the residues of oilcakes have considerably increased the pasturage, but as they increase grasses at the expense of the leguminous herbage these residues are likely to do more harm than good during the first two years after improvement has been begun.

RESULTS AT COCKLE PARK FROM THE FOURTH TO THE EIGHTH SEASON.

At the end of the third season those of the plots which originally received 100 lbs. phosphoric acid per acre had the dressing repeated. Except in one case we are not able to follow the effects of this treatment, for most of the experiments have only completed the fourth year; but at Cockle Park, which from the uniformity of its plots and the consistency of its results must be looked upon as the most satisfactory of all the experiments, we are fortunate in having a continuous record for eight years, and to this record we turn for further guidance in the management of poor pastures of this type.

Table II presents a summary of the results at Cockle Park for the eight seasons ending with 1904. The figures give the increase made by sheep *in excess of the increase on untreated land* for three periods, viz. 1897-99, 1900–02, 1903–04[1]. The increase for each period is the average annual increase. The general character of each of the eight seasons 1897–1904 is indicated by the increase made on Plot 6, which was unmanured. This increase was:

1897	37 lbs. per acre	1900	44 lbs. per acre	1903	41 lbs. per acre
1898	53 ,, ,,	1901	23 ,, ,,	1904	33 ,, ,,
1899	48 ,, ,,	1902	41 ,, ,,		
	,,	Average	36 ,, ,,	Average	37 ,, ,,

Average for eight years 40 lbs. per acre.

[1] For the figures for season 1904 the writer is indebted to Professor Gilchrist of the Armstrong College, Newcastle-on-Tyne.

TABLE II. Pasture Experiment at Cockle Park, Northumberland. Results for three years 1897–99, three years 1900–02, two years 1903–04, and eight years 1897–1904. The figures give the average Annual Live-Weight Increase made by Sheep *in excess of the increase on, the unmanured plot.* The last Column gives the net Annual Increase obtained by deducting from the gross Increase, the Increase necessary to pay for the Manures. Grazing Plots 3 acres. Figures "per acre."

Plot	TREATMENT	Annual Live Increase during			Eight years 1897–1904		
		Three years 1897–99	Three years 1900–02	Two years 1903–04	Average Live Increase	Annual Cost of Manures in terms of Increase	Net Annual Live Increase or Decrease (–)
		lb.	lb.	lb.	lb.	lb.	lb.
1	Decorticated Cotton Cake fed on Plot, 1897, 1898, 1903, 1904, total, 16 cwt.	64	31	152	74	?	—
2	4 tons Quicklime, 1897 and again in 1903	2	20	13	12	40	–28
3	200 lbs. Phosphoric acid (P_2O_5) in Basic Slag in 1897, nothing since	107	85	55	86	9	77
4	100 lbs. Phosphoric acid in Basic Slag in 1897, and again in 1900	44	95	68	69	9	60
5	100 lbs. Phosphoric acid in Superphosphate in 1897, and again in 1900	42	90	47	61	14	47
7	Super. as for Plot 5 and 50 lbs. Potash (K_2O in Sulphate) in 1897, 1898 and 1903	54	92	60	70	25	45
8	Super. as for Plot 5 and 10 cwt. ground Quicklime in 1897, 1899 and 1903	55	120	72	83	28	55
9	Super. as for Plot 5 and 20 lbs. Nitrogen in Sul. Am. in 1897, 14 lbs. in 1899, 17 lbs. in 1900, and 17 lbs. in 1903	48	79	49	60	30	30
10	100 lbs. Phosphoric acid and 17 lbs. Nitrogen in Dissolved Bones in 1897 and again in 1900	48	88	57	65	26	39

Note. The prices of the Manures on which the figures in Column 7 are based, are the prices at Cockle Park. In Table I the prices of the Manures were the average prices at the different stations.

The cost of the manures has been expressed in terms of Increase and the net increase has been entered in the last column on the assumptions that live increase is worth 35*s*. per cwt. and that the entire cost of the manure is paid for in eight years.

In the light of further experience we may now review the conclusions come to on p. 130.

With respect to the phosphatic manures used on Plots 3, 4, and 5 the figures in Table II confirm the results in Table I. It is now clear, not only that the dressing of basic slag given to Plot 3 has been more profitable than that applied to Plot 4, but that by dividing the dressings of slag, and using half quantities at an interval of three years, the effect of the manure has been considerably reduced. (This point is of great practical importance.) At the end of eight years the superiority of basic slag over superphosphate is pronounced. At the end of the fifth season the increase on Plots 4 and 5 was equal, but during the past three years Plot 4 has rapidly improved its position.

The results obtained from potash manuring during the second period were disappointing. In 1902 however an improvement began. Plot 7 now grows clovers better than Plot 5, and it is clear that the latter plot is beginning to suffer from a lack of potash.

During the first three years Plot 3 attracted most notice but in the second and third periods Plot 8 (super. and lime) has been the most interesting, as well as the most productive plot in the field. It was most fortunate that the combination of manures here used found a place in the scheme, for by the action of lime on Plot 8 we are enabled to explain the whole effect of basic slag.

The influence of ground quicklime became marked in 1900, and was very striking in 1901 and 1902. The notable increase during these years was not, however, due to the action of lime on the Leguminosæ, but to its influence on the Gramineæ. The development of such grasses as crested dogstail, golden oat-grass, Yorkshire fog, cocksfoot and sweet vernal was astonishing; Plot 8 began to assume the appearance and character of a meadow, and difficulty was experienced in grazing it properly. In spite of some waste of grass, however, the sheep benefited greatly by the change, as the mixed character of the herbage prolonged the grazing season, and the grass came earlier in spring and persisted into the autumn. Plot 8 stood out conspicuously at two seasons—in spring, when it turned green before any of the other plots, and in July when the grasses were in flower.

The action of lime on the herbage of Plot 8 was obviously due to its effect on the organic matter accumulated in the surface soil by clover. Lime promoted the decomposition of this organic matter and thus aided the grasses by increasing the supply of nitrates.

The quicklime applied to Plot 2 has had little effect, because here

the lack of phosphates prevented the growth of clover, so that there has been no rapid accumulation of organic matter in the surface soil.

A slight improvement was noticeable in Plot 2 during the second period, and this may be attributed either to the gradual decomposition of intractable organic and mineral compounds under the influence of lime, or to the somewhat improved texture which lime would be likely to give the raw surface soil.

The further experience of cake-residues and of artificial nitrogenous manures gained on Plots 1, 9, and 10 at Cockle Park confirms the conclusion with respect to their value already stated (see p. 131).

Influence of Manures on Leguminosæ and on Gramineæ.

It is clear from a study of the results of these five pasture experiments that basic slag is the most useful of the manures tested, and that it ought to be employed liberally as on Plot 3, not in small dressings as on Plot 4. To those who are accustomed to use manures on arable land or on old pastures of good quality, and who have not followed the changes produced by basic slag in the herbage of poor clay soil pastures, the foregoing statement of results and conclusions will suggest many questions.

Why do phosphates produce so great and so rapid an increase? How can a 10 cwt. dressing of basic slag cause more than twice the increase produced by 5 cwt.? Why are two 5 cwt. dressings of slag inferior to a single 10 cwt. dressing? Why should slag and superphosphate produce nearly equal results for a time, and why should the soluble manure then fall behind? Why are nitrogenous manures injurious? These are some of the questions likely to be suggested by the experiments. A study of tables of figures will not supply answers, but the pastures themselves, when closely examined, clearly explain the action of the manures.

These poor worn-out soils furnish all the conditions necessary for the healthy and vigorous growth of Leguminosæ save one—a supply of phosphates. When phosphates are applied in manure a very rapid increase in the leguminous herbage takes place, and in a year or two a green carpet of white clover, or a loose tangled crop of medick covers the barren surface. A rapid improvement in the quality of the surface soil immediately sets in, the herbage is converted into manure by stock, roots open up and aërate the dense harsh sub-soil, organic matter accumulates, and atmospheric nitrogen is fixed by the nodule organisms. Thus because

of the extraordinary rapidity with which clover can grow and spread under favourable conditions, the soil becomes closely covered with vegetation until it bears some resemblance to the virgin state in which the plough found it, and is—by natural processes—enriched until it again possesses some of that fertility of which the plough robbed it.

Phosphates produce little or no direct effect on grasses, but as soon as clover has improved the surface soil grasses begin to spread. If at this stage the soil is supplied with lime (either the lime of basic slag, or quicklime) decomposition and nitrification go on rapidly and the grasses grow very quickly. As the result therefore of the action of phosphates on Leguminosæ, and of lime on the Gramineæ, we have at the end of three or four years a mixed herbage of fair quality covering the formerly impoverished pastures.

In the case of Cockle Park, Yeldham, and Cransley the 10 cwt. dressing of basic slag produced twice, or more than twice, the increase of the 5 cwt. dressing, because, apart from the lack of phosphates, the soil was capable of carrying a very heavy crop of clover or medick, and the larger dressing of manure enabled these plants to take full advantage of the favourable natural conditions. The stronger root development that followed the use of an ample supply of phosphoric acid enabled the plant to collect greater quantities of moisture, and to double or treble its growth.

Clovers appear to be as well suited by superphosphate as by basic slag, but the latter contains lime, which assists the grasses, and this is why Plot 4 has of late years surpassed Plot 5 at Cockle Park. The results obtained on Plot 8 show that the decline of Plot 5 cannot be entirely or even largely due to a more rapid exhaustion of the soluble, than of the insoluble phosphates.

Two separate 5 cwt. dressings of basic slag, such as were applied to Plot 4, are inferior to a single 10 cwt. dressing as used on Plot 3, because as a result of the first manuring grasses spring up in the pastures and come into competition with clovers. Clovers are unable to develop in the face of competition, and for this reason they do not benefit fully by a second application of manure. Since it is most desirable that clovers should have the fullest scope for development during the first two or three years, the use of any manure likely to stimulate grasses into immediate and rapid growth is to be condemned. Farmyard manure, sulphate of ammonia, and nitrate of soda should not be used until two years after phosphates have been applied.

That the presence of lime promoted the decomposition of organic

matter and acted as a nitrogenous manure at Cockle Park and Cransley, was quite evident both from the colour of the grasses in early spring and their subsequent development. So far as he has been able to judge from inspection of the plots the writer thinks that ground lime has had little direct effect on the clovers.

The opinions expressed respecting the influence of phosphates on clover and on the effects of the competition of grasses with clover, are based partly on evidence derived from inspection of the plots and partly on experiments.

As these two points are of great importance in explaining the action of phosphatic manures, the experimental evidence will be given.

In the winter of 1902–03 the writer was consulted about the improvement of a poor clay soil at Wendon Lofts in Essex. The general character of the pasture was that of the clay soils on which phosphates produce so marked an effect, but in this case a close search revealed no Leguminosæ; it was decided therefore not to apply phosphatic manures to the field; but a small area was set apart for an experiment. Plots were marked off and treated with basic slag, kainit, and lime in the end of January. The manures were used both alone and in combination. In March white clover seed at the rate of 12 lbs. per acre was sown on certain plots, so that the clover occupied both untreated land, and land previously manured with basic slag. Owing to the hard state of the surface the seed could not be harrowed in, and it was sprinkled on the surface and left. The wet summer of 1903 was favourable to the experiment, and in the autumn, although no effects of the manuring could be detected, the young clovers were found to have established themselves. In 1904 the results were very marked. None of the manures and none of the combinations of manures applied to the original soil produced any effect, but where clovers had been sown after the application of basic slag, there was the luxuriant growth which one expects in pastures where Leguminosæ are present. In the absence of basic slag the clover plants did not develop, but remained throughout the season in an impoverished state. From the Wendon Lofts experiment we may conclude that in the absence of Leguminosæ phosphatic manures will not increase the produce of poor clay pastures, at least during the first and second years after application.

That the enormous development of white clover which follows the use of basic slag is only possible on a soil unoccupied by grasses must

be evident to anyone who studies the habit of the clover plant. Where phosphates are abundant its growth for the first two or three years after manuring seems to be limited only by the quantity of moisture it can secure. The runners spread all over the surface, and rooting freely wherever the soil is bare the plant contrives to supply itself with an abundance of moisture on clay and heavy loam soils, even in moderately dry weather; but directly grasses spring up not only is the surface occupied so that clover runners cannot root, but the surface is robbed of its moisture so that the plant cannot grow quickly. In ordinary seasons the long runners of white clover may always be found in the coarse tufts of grass which spring up on poor clay soil pastures, but towards the close of the past dry summer the writer searched in vain for runners in the grass tufts on three experimental pastures; the grasses had used up all the surface moisture, and clover had disappeared.

Basic slag seldom effects any great change on old pastures where there is a close turf, for the surface being already fully occupied clover cannot spread much. This manure is also likely to fail on poor, moist pastures which have become covered with a layer of partially decomposed vegetable matter, for until the peaty covering has been reduced by lime clover runners cannot root freely.

The effect of the competition of grasses on the progress of clover was very clearly shown by Plots 4 (basic slag) and 5 (superphosphate) at Cockle Park in seasons 1900–02. For five years, as has already been pointed out, these plots ran a very close race. At the end of the first three years Plot 4 was ahead of its rival. In 1900 however, after the second application of manure had been given, Plot 5 improved its position. This result was attributed to the soluble condition of the phosphate, and it was believed that Plot 5 would now begin to deteriorate; in 1901, however, it still further improved its position. As the season progressed a marked difference was observable in the herbage of the two plots which explained the improvement. On Plot 5 there was a fine healthy crop of white clover and the chief grass was bent, which owing to its loose, open habit of growth is clover's least formidable competitor[1]. On Plot 4, as the result of the action of the lime in the basic slag, crested dogstail, golden oat-grass, Yorkshire fog, and other grasses were much more numerous than on Plot 5, there was less bent-grass, and the clover plants though numerous

[1] In some respects *Agrostis*, by providing shelter in winter and spring, may be regarded as an ally.

were smaller and distinctly inferior to those on Plot 5[1]. In 1902 the clovers began to disappear, and as the gramineous herbage is inferior, Plot 5 has somewhat rapidly deteriorated of late years, but it is clear that the recovery in 1900 and 1901 was due to the fact that the grasses on Plot 5 did not then form so close a sward as they did on Plot 4.

The failure of phosphatic manures to improve the Trowse pasture was not due to the absence of Leguminosæ as at Wendon Lofts, but to the absence of a continuous and sufficient supply of moisture near the surface. On light soils occupied by grasses clover cannot produce long runners. When the conditions are favourable white clover may make runners a yard or more long, but on light soils they seldom exceed 6 to 12 inches. At Trowse the Leguminosæ, limited in their water supply, could not take advantage of the phosphates, and as it was evident that except in abnormally wet seasons the clover would never be able to benefit by, or to pay for the heavy dressings of phosphates so profitably employed on clay soils, the experiment was abandoned at the end of two years. The results from Plot 7 indicate indeed that it was a potash and not a phosphatic manure that was wanted on the Trowse soil, but large quantities of a potash manure would have been quite as inappropriate as heavy dressings of a phosphate, for on this pasture the vegetation is not of a kind that can absorb and utilize large quantities of manure. The building up must be gradual, and in improving it small dressings of mixed manures should be applied at frequent intervals.

Even on clay soils the season's rainfall is an important factor in the spread of clover, and occasionally on soils which crack much and become very dry on the surface phosphates may fail to produce their usual effects[2].

Absence of Leguminosæ at Wendon Lofts and of moisture at Trowse rendered phosphatic manures useless; there is a third cause of failure which may be noticed here. Some soils, especially medium or light loams, which might otherwise benefit by an application of phosphates, fail to respond because of a deficiency of potash. From the experiments described above it seems safe to conclude that clay soils will seldom fail at the outset for this particular reason, but sooner or later the

[1] The difference in the type of herbage on Plots 4 and 5 was very marked in July, 1901, and visitors to Tree Field expressed astonishment that the source of the phosphoric acid could exercise so great an influence on the appearance. At the same time the value of the two pastures for grazing purposes was very equal, and parties of farmers could never agree as to which was worth most.

[2] See Annual Report Camb. and Counties Agric. Education Scheme, 1898, p. 16.

available potash in the surface soil will become exhausted and the pasture will suffer. There is evidence that about the sixth season the absence of potash began to be felt by the clovers on Plot 5 at Cockle Park, and in another Northumberland experiment where basic slag in conjunction with kainit was very successful, and where kainit used alone was useless, basic slag began to lose its effect in the third season because of a lack of potash.

MANAGEMENT OF POOR PASTURES.

We are now in a position to lay down rules for the guidance of those who wish to improve poor pastures on clay soils.

In the great majority of these pastures Leguminosæ are numerous, and the first consideration must be the stimulating of the Leguminosæ, and especially of white clover, into active growth. The experiments clearly indicate that the greater the development of the clovers during the first year or two the greater and more lasting will be the improvement of the pastures. To obtain the best results it is essential that the clover should be enabled to make rapid growth before it has to face the competition of the grasses, and therefore the proper course is to apply as much phosphatic manure as the Leguminosæ present can utilize. In most cases when in doubt it is wise to apply less rather than more artificial manure than is likely to be required, but here it is best to err on the other side. Phosphates are not expensive, and every shilling's worth utilized by clovers in the first two years is likely to bring in a sevenfold return. The best quantity will of course vary under different conditions. When white clover is the leguminous plant, when bent is the predominant grass, and when the climate is moist, from 10 to 12 cwt. of basic slag per acre would be a suitable dressing. When medick, suckling clover and bird's-foot-trefoil represent the Leguminosæ, when the grasses are mixed, and when the climate is dry, from 7 to 10 cwt. of basic slag may be recommended. Under certain conditions superphosphate might prove superior to slag, but these conditions are not likely to occur often.

During the first two years any treatment calculated to strengthen the Gramineæ must be avoided; but after the first two or three years have passed the clovers will inevitably begin to diminish in quantity and grasses will spring up. If care be exercised a close turf will now begin to form and the barren field will gradually assume the appearance of an old pasture. Detailed directions cannot be given for the manage-

ment of the pasture at this stage; the treatment will vary in different cases. The aim must now be not to encourage clovers only, but to produce a mixed herbage. Many of the better grasses will be weak and the closest attention must be given to the grazing of the surface. If the young grasses are allowed to seed, or if they are too closely grazed, they may die off; and if coarse grasses, which are always present, are permitted to take possession an inferior pasture will result. When such grasses as bent and Yorkshire fog are allowed to cover the surface a close turf will not form, the opportunity of establishing better grasses in a soil enriched by clover residues will be lost, and an equally favourable opportunity of effecting a permanent improvement in the pasture will not again occur for many years.

From the third to the sixth year is likely to be a critical period in the history of the pasture, and the manuring should be on a liberal scale, even if the cost is somewhat high. A light dressing of farmyard manure, if available, would do great good, or failing this, the stock should be liberally fed with oilcake (preferably with decorticated cotton cake), or artificial manure may be applied. A mixture of 2 cwt. superphosphate, 2 cwt. kainit, and ½ cwt. fish meal per acre, costing about 13*s*., would probably prove useful in the spring of the fourth and sixth seasons, and if the soil were damp, and the herbage were late in growing in spring, an occasional application of 10 to 15 cwt. slaked lime per acre in February would be likely to assist nitrification and the spread of the grasses.

Medick, bird's-foot-trefoil and suckling clover appear to be of much less value than white clover as improvers of soil, and when white clover plants are few (one to a square yard) or are absent, the plan of scattering some seed on the surface, adopted with success at Wendon Lofts, may be tried. Occasionally on a soft surface the seeds may be roughly harrowed in, but the surface of a clay pasture will usually be too hard to yield to the tines of a harrow. By repeated harrowings in wet weather a slight surface tilth was obtained on a clay soil at Cockle Park, but the results did not justify the cost. The Wendon Lofts plots were sown in spring, and the clovers were fortunate in meeting a favourable season, but even in the dry season of 1904 a case of successful sowing has come to the knowledge of the writer. In the South of England it is probable that autumn sowing would usually give better results than spring sowing, but the point has still to be tested. At Wendon Lofts seed was sown at the rate of 12 lbs. per acre, but from the appearance of the crop in 1904 it was evident that 3 lbs. would have been enough. Those who

wish to experiment on sowing clover in this way are recommended to try from 3 to 6 lbs. per acre. The seed of wild white clover was sown at Wendon Lofts, but this is scarce and expensive, and it seems likely that ordinary white clover seed would serve the purpose.

Where Gramineæ are very poorly represented it would probably pay to sow small quantities (3—5 lbs. per acre in all) of such hardy grasses as crested dogstail, hard fescue, and timothy, either with the clover seed, or a year later. It would not be necessary to sow much, for if the grasses got a footing in the pasture they would spread quickly after the soil had been enriched by clovers, and it would not be prudent to spend more than a small sum on the attempt to introduce grasses, for they do not establish themselves so readily as white clover, and are very liable to die off in unfavourable summers.

DISCUSSION OF THE METHOD.

It will have been remarked that the returns from some of the manures used have been unusually high, and, as the method of the experiment is new and has met with some criticism, it will be desirable before concluding to examine it and to discuss its accuracy and limitations.

There are four points in the method to which attention may be directed in this connexion, viz.: (1) the small number of sheep employed; (2) the small size of the grazing areas; (3) the propriety of depasturing by sheep only; (4) the value of live-weight increase as a test of progress.

The number of sheep usually varies from six on the unmanured plot to twelve on the best plots. In some years as few as four animals have been put on an untreated plot. In such small lots there is a danger that the results may be unduly affected by the quality of the individual sheep in the different lots. The writer has carefully considered this question and has compared the increase made by individual sheep on grass in a number of cases, and he does not think that the above cause could have produced any serious errors in the results. As compared for example with sheep on winter diet, sheep on grass make very uniform gains, and if reasonable care is taken in the selection and supervision of the sheep even the smaller lots will not suffer from the influence of the individual.

The second point is one raised by farmers. Some flockmasters contend that it is impracticable to fold sheep on three acres of land

for from 16 to 20 weeks, because the health of the sheep must suffer, and therefore the increase made will bear no relationship to the quality of the pastures. In answer to this it may be pointed out that the number of sheep put on the grass rarely exceeds four animals to the acre, so that the land does not get foul, and further that as a matter of fact the sheep remain perfectly healthy. The casualties at Cockle Park for the first five seasons were but little over 2 per cent., and in almost every case the casualties were caused by the maggot-fly or the "gid" cyst (*Cœnurus cerebralis*), and had no connexion with the system of grazing. On some of the plots sheep did cease growing, but the cessation was due to unsuitable or scanty pasturage, and all the sheep were affected alike; no diseases were set up by a foul condition of the pastures.

The third criticism of the method is raised from the standpoint of the pasture. It is contended that when grass land is depastured by sheep only it does not always get a fair chance, and that much better results would have been obtained from the experimental pastures if a mixed stock of cattle and sheep had been kept.

This objection is a sound one. It may at once be admitted that better results would have been got if a mixed stock had been put on the grass; but it would have been impracticable to have used cattle in the particular cases under discussion, and there would be many difficulties in carrying on the experiments on such a scale as would have admitted of the grazing of both cattle and sheep. The difficulty in grazing with sheep only is that strong-growing grasses cannot be kept down, and when they run to seed the quality of the pasturage deteriorates. The poor pastures in their natural state were easily kept under, but when improved by manuring more or less of the grass was always wasted. The stronger the growth of the grasses the greater was the tendency to waste, and under ordinary farming conditions the results obtained from manures would always have been greater than those shown by the experimental plots. Plots 9 and 10 receiving nitrogenous manures suffered most from this limitation in the method, but the injury done them was small, and under no circumstances could the returns from these plots have been such as would have altered the conclusions stated on p. 131.

The results from some pastures are more affected by grazing difficulties than others, and in the group of stations now under notice Yeldham suffered most. Under the influence of certain of the manures heavy crops of grass were produced during the later months of the season at this station, but the sheep derived no benefit from the

pasturage, and the manures have therefore received no credit for the increased growth.

The fourth objection to the method lies in the use of live-weight increase as a measure of the value of the manures. Live increase does not contain a fixed proportion of mutton. In lean animals the increase is more watery in character than in fat, and the increase made on the worst plots where the sheep remain thin throughout the season is therefore worth less than the increase on the best plots where the animals are in higher condition. An attempt to meet this difficulty has been made by adjusting the numbers of the stock to the quality of the pasture, and on all the improved plots the live increase has approximately the same value; but the sheep on the unmanured land, however few in number, always remain in very lean condition, and the increase they make is worth less per lb. than the increase made by the fatter sheep on the manured land.

The limitations in the experimental method are therefore not of a serious kind. There is a tendency to under-estimate the extent of the improvement due to manuring, but it is much safer to under-estimate than to exaggerate. As between the different plots this method holds the balance very evenly, and month by month there is a close agreement between the appearance of the herbage and the gains made by the sheep. From the detailed reports on the experiments evidence of this close agreement may be obtained, and the following example may be cited.

During the years 1900–02 the writer frequently visited the Cockle Park experiment in company with experienced farmers, and notes were made on the appearance of the pastures. In 1900 Plot 5 was considered slightly inferior to Plot 4, in 1901 the positions were reversed, but in 1902 Plot 4 was again the better. In 1900 Plot 10 was very similar to Plot 9, in 1901 it was better than Plot 9 but not equal to Plot 5. In 1902 Plot 10 contained a little more grass than Plot 5. In each of the seasons Plot 2 was considered very inferior to, and Plot 8 very much better than, any of the four plots already mentioned. The actual increase in pounds per acre made by the sheep was as follows:

		PLOT 2.	PLOT 4.	PLOT 5.	PLOT 8.	PLOT 9.	PLOT 10.
		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
1900	...	60	139	137	159	128	134
1901	...	41	107	115	144	98	100
1902	...	68	146	127	164	120	139

Summary.

1. The results of six experiments in the manuring of poor pastures are described. The experiments were made in the counties of Northumberland, Northampton, Cambridge, Essex, Norfolk, and Hants. The results are given for a period of three years at all stations (except Norfolk, two years), and for two further periods of three and two years at the Northumberland station.

2. In Norfolk on a light soil a potash manure slightly improved the pasture; the other manures had no influence on the yield. At the remaining five stations on heavy soils phosphatic manures produced highly profitable returns. In the first period, the use of other manures was not justified by the results. Where, however, the experiment was continued for eight years, lime proved profitable in the second, and potash in the third period. Under the special conditions of the experiment nitrogenous manures were either injurious or but very slightly increased the yield.

3 From the results given in the tables on pp. 128 and 132, and from frequent examinations of the character and progress of the pastures the following explanation of the effects of the manures is offered: Phosphatic manures stimulate into rapid growth such Leguminosæ as white clover (*Trifolium repens*), suckling clover (*T. minus*), and medick (*Medicago lupulina*), which are almost everywhere present in a starved, undeveloped state on barren pastures. These soon cover the soil and in many ways improve its quality. In the third or fourth year Gramineæ begin to spread rapidly in the improved soil, the Leguminosæ at the same time diminish, and the pasture assumes a mixed character. The presence of lime greatly assists the spread of grasses. For the first few years the available potash of a clay soil appears to supply the needs of the Leguminosæ. After a time, possibly in from four to six years, on ordinary poor pastures, potash manures become necessary. In some cases it is likely that the need for potash may be much longer delayed.

4. Specific directions for the treatment of poor pastures are given. These directions are based on the following considerations:

(1) The greater the development of the Leguminosæ during the first three years the greater will be the ultimate improvement.

(2) The growth of clovers is much hindered by competition with grasses, therefore any treatment likely to stimulate grasses must be avoided for the first two years.

(3) It is impossible to maintain a purely leguminous herbage, clovers will partly (sometimes almost completely) disappear in the course of three or four years; further, a mixed herbage is desirable from the grazier's standpoint. It is desirable therefore to encourage grasses from the third or fourth season onwards, and the treatment should be directed towards establishing a mixed herbage.

(4) In the formation of a mixed herbage manures are necessary, but careful depasturing will usually be of greater importance than manuring.

5. Since it contains both phosphoric acid and lime, basic slag is the most useful manure with which to begin the improvement of poor clay pastures. In the second stage the residues of oilcakes fed on the land are likely to give the best results, but with these other manures may be necessary.

6. Cases of the failure of phosphatic manures on soils are considered, and it is shown that failures may be due to (1) absence of Leguminosæ; (2) absence of conditions suitable for the active growth and full development of Leguminosæ, such as an insufficient supply of moisture, injury to runners and roots through cracking of the surface soil, competition with the grasses of an old turf, or lack of available potash.

CALCIUM CYANAMIDE.

By A. D. HALL, M.A.,

Director of the Rothamsted Experimental Station. (Lawes Agricultural Trust.)

CALCIUM Cyanamide represents the first attempt on a commercial scale to bring atmospheric nitrogen into a state of combination, to manufacture, in fact, an artificial manure containing nitrogen derived from the air. The starting-point for the manufacture is the well-known substance calcium carbide, which is produced by heating in the electric furnace a mixture of chalk and coke or some other form of carbon. The calcium carbide, now so generally employed for generating acetylene for lighting purposes, is almost wholly made where cheap power to produce electricity can be obtained from a waterfall, and the manufacture of calcium cyanamide must naturally take place alongside, so as to secure a cheap supply of carbide. The remaining process is simple enough; the calcium carbide is reduced to a coarse powder, placed in a vessel resembling a gas retort and brought to a temperature approaching white heat, when a current of nitrogen gas is led over it until combination ceases. The result is a compound containing nearly 20 per cent. of nitrogen, crude calcium cyanamide, the formula of which when pure would be represented by $CaCN_2$. The nitrogen required in the manufacture is obtained from the air in the simplest way by passing air through a heated cylinder packed with copper turnings; the oxygen combines with the copper and the nitrogen passes forward into a gasholder until required. The copper is regenerated by passing a current of coal-gas through the heated cylinder. The resulting crude calcium cyanamide is a fine black powder, which decomposes rapidly when heated with water under pressure, and slowly with water at ordinary temperatures, into calcium carbonate and ammonia, in accordance with the equation

$$CaCN_2 + 3H_2O = CaCO_3 + 2NH_3.$$

Cold water and the action of acids extract a substance dicyandiamide $(CN_2H_2)_2$, noteworthy as containing two-thirds of its weight of

nitrogen. This substance is of no service to plants, but appears to have some use in connection with the manufacture of high explosives. From the crude calcium cyanamide it is easy to prepare the cyanides of sodium or potassium, and sodium cyanide manufactured in this fashion is now on the market.

The nitrogen in the crude calcium cyanamide is best determined by digesting it with strong sulphuric acid by the usual Kjeldahl's method.

The manufacture of crude calcium cyanamide has not yet been taken up on a large scale, a model plant is in operation in Berlin capable of turning out quantities of about 1 ton per diem, and arrangements are being made with other firms to develop the process commercially.

Through the kindness of the Cyanid Gesellschaft of Berlin the Rothamsted Experimental Station was furnished with 50 kilos of the material, containing 19·7 per cent. of nitrogen, in the spring of 1904. It was then too late to use it for any cereal crop, since it cannot be employed as a top dressing, but arrangements were made for experiments with roots.

As a manure it should be applied to the soil some little time before the seed is sown and should be lightly ploughed in, lest any loss of ammonia take place. It cannot well be mixed with other manures; with superphosphate, for example, the reaction is somewhat intense and the whole mass becomes very hot. It was decided to compare its action with that of an equivalent amount of nitrogen in the shape of sulphate of ammonia, superphosphate and sulphate of potash being equally supplied to both. The Rothamsted soil is a somewhat heavy stony loam, almost a clay in the subsoil; the surface soil contains a fair supply (from 1 to 3 per cent.) of carbonate of lime, so that sulphate of ammonia is always an effective source of nitrogen.

The following table shows the comparative results obtained with Mangels, Swedes, and Mustard respectively.

It was noted in each trial that the plot receiving sulphate of ammonia made the better start and was distinctly more advanced, as long as the roots were small. In the trial with swedes the differences were very pronounced until the end; this was a poor piece of land, very much out of condition, and though a very regular plant was obtained and a good start made, the roots grew but little during the autumn, owing to the dryness of the season. In the trial with mangels, the plants receiving sulphate of ammonia had the better appearance throughout, the leaves were of a darker green and seemed more luxuriant. Owing to insect attacks, however, both plots lost rather

CALCIUM CYANAMIDE *versus* SULPHATE OF AMMONIA, AT ROTHAMSTED, SEASON 1904.

	Produce per acre				
	Mangels		Swedes		Mustard
	Roots	Leaves	Roots	Leaves	
	Tons	Tons	Tons	Tons	Tons
1. Sulphate of Ammonia	19·71	2·95	13·40	1·31	4·37
2. Calcium Cyanamide ..	20·25	2·54	9·98	0·95	4·16

Manuring—For *Mangels*—200 lb. Superphosphate (37 %), 200 lb. Sulphate of Potash, and 300 lb. Sulphate of Ammonia or 315 lb. Calcium Cyanamide, per acre.
For *Swedes*—4 cwt. Superphosphate (37 %), 1 cwt. Sulphate of Potash, and 200 lbs. Sulphate of Ammonia or 210 lb. Calcium Cyanamide, per acre.
For *Mustard*—4 cwt. Superphosphate (37 %), 1 cwt. Sulphate of Potash, and 200 lb. Sulphate of Ammonia or 210 lb. Calcium Cyanamide, per acre.

Mangels—Seed sown, May 7. Crop harvested, Nov. 4. Plants on (1) 76 %, and on (2) 77·3 % of possible.

Swedes—Seed sown, May 25. Crop harvested, Nov. 15. Perfect plant.

Mustard—Seed sown, July 27. Cut, Sept. 21.

a high proportion of plants, so much so that I should not attach much weight to the result. In the trial with mustard the cyanamide plot was the slower to start, but when in full flower no difference could be seen between the two plots.

Speaking generally the trials do not warrant any definite conclusion as to which is the better source of nitrogen, calcium cyanamide or sulphate of ammonia; two of the three experiments would make the cyanamide as good a source of nitrogen as sulphate of ammonia, but as has already been stated one of these experiments may be considerably in error. The third trial, a very uniform and even experiment, which looked trustworthy, was decidedly in favour of the sulphate of ammonia, but on the other hand on this plot the cyanamide by mistake had been mixed with the other manures and burnt earth before sowing. Again the stoppage of growth through the drought did not give the cyanamide as good a chance, if we may assume it requires time and plenty of moisture to set free all the ammonia.

There can be little doubt however that calcium cyanamide is an effective nitrogenous manure, though more extended experiments are necessary to decide whether the unit of nitrogen is worth more or less in its case than in sulphate of ammonia.

VOLUME I MAY, 1905 PART II

VARIATION IN THE COMPOSITION OF COWS' MILK.

A RÉSUMÉ OF RECENT EXPERIMENTAL WORK IN GREAT BRITAIN.

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THE object of the present communication is to collect together and compare the data obtained in the principal investigations which have been carried out in this country during the past five years into the variations in composition of the milk of the cow. The results of many of these experiments have been published only in annual reports or as special bulletins with limited and more or less exclusively local circulation.

For this latter reason it is impossible for the writer to be absolutely certain that all experiments which might fairly claim notice have been included in the *résumé*, but every effort has been made to render it as complete as possible in this respect. Further, in view of the admitted difficulty in obtaining samples of milk representative of the bulk from which they are taken, even when the sample is drawn immediately on the completion of milking, no account has been taken of published data based on samples taken under other conditions.

The fact has also not been overlooked that many experiments not alluded to in this summary have been carried out from time to time by practical farmers on their own farms, and reported in more or less detail in the agricultural periodicals; but, whilst not intending thereby to impugn the accuracy of any of these experiments, it has been thought advisable to limit the survey to such experiments as have been carried out by trained investigators connected with agricultural educational institutions or the great agricultural societies.

The experiments reviewed were carried out in or subsequent to the year 1900. This period has been adopted in view of the fact that a more or less complete summary of the data obtained up to that year is generally available in the Report of the "Milk Standard" Committee[1] appointed in that year by the Board of Agriculture, and in the Minutes of Evidence[1] on which that report is based. Moreover much of the subsequent experimental work has been occasioned or considerably influenced by the regulations for the sale of milk introduced by the Board as the outcome of the deliberations of that Committee.

The evidence given before the Committee revealed a wide disparity of opinion on many important points. Further it is noticeable that very little precise information based upon samples drawn in the cowhouse immediately after the milking was at that time available concerning the diurnal variations in the composition of the milk of individual cows, and even of the mixed milk of herds.

This fact had already attracted attention, and led to the carrying out, first in 1900 by Mr Herbert Ingle, of the (then) Yorkshire College, and subsequently by other investigators in connexion with similar institutions, of the investigations into the nature and extent of these variations, and the causes to which they are attributable, which form the subject of the present communication.

A list of the investigations dealt with—numbered for convenience of reference—will be found on p. 175, together with data which may be helpful in comparing the results. Particulars are also given in this table of the sources from which the results have been derived.

In the Scottish investigations (9, 11)[2] practically all the cows were of Ayrshire breed, but in all other cases the cows were of shorthorn breed.

It will be noted that the conditions under which the various experiments were carried out (*e.g.* in respect of season, times of milking, etc.) differed widely, so that it is impossible to institute a fair comparison throughout of the results obtained in the different investigations. In this connexion the writer can indeed do little more than direct attention to any such differences, and suggest the degree of importance which, in his opinion, should be attached to each.

In the following pages the chief influences which have been investigated in the different experiments are dealt with in separate sections. It is hoped that a more interesting and useful survey of

[1] Published in 1901.

[2] Nos. 9, 11 in the list on p. 175. This mode of reference to the individual investigations is employed throughout the *résumé*.

the results has thereby been arrived at than could be obtained by reviewing each investigation separately. For connected accounts of each investigation reference must hence be made to the original memoirs.

METHODS OF ANALYSIS.

The analysis of the samples has in practically every case been limited to estimations of the proportions of fat and total solids.

The *fat* has almost invariably been estimated by the Gerber method, and opinion is unanimous as to its accuracy and reliability. Ingle records however (1 *a*), that the use of formaldehyde as a preservative renders the curd much more difficult of solution in the mixture of sulphuric acid and amyl alcohol. He subsequently used an ammoniacal solution of potassium dichromate for preservative purposes. Collins (4 *a*) used either a mixture of chloroform and ether or a mixture of chloroform and alcohol containing about 1 per cent. of formaldehyde. The small quantity of the latter used had no disturbing effect.

The *total solids* have in many cases been estimated directly by evaporation, but more frequently the more rapid indirect method based on Richmond's well-known formula, and involving only determinations of the fat-content and specific gravity of the sample, has been used. The accuracy of this method, as compared with the direct estimation, has apparently been tested in comparatively few cases, but all agree that the concordance is usually very close, the difference between the two values rarely exceeding ·1—·2 per cent., the lower value being usually that obtained by the indirect method.

Reference may also be made here to the investigations carried out in the Government laboratories into the possibilities of error in the analysis of sour milks by the ordinary methods[1]. It is found that the errors are almost entirely confined to the estimation of the solids-not-fat, for which low results are obtained owing to the formation of volatile products by fermentation. It has further been found that the deficiency can be calculated with fair accuracy from the amounts of alcohol, volatile acids, and ammonia present in the sample.

A passing reference may also be made to the further investigations of Thorpe and his assistants into the variations in and interdependence of the physical and chemical criteria of the fat of butter, dealt with in

[1] Thorpe, *Journ. Chem. Soc. Trans.* 1905, 206.

the analysis of the same[1], although they do not strictly fall within the scope of the present review.

Influence of Interval between Successive Milkings.

This question has been definitely investigated in two separate experiments, viz., at Garforth in 1902 (1 *c*), and at Cambridge in 1903 (8)

In the Garforth experiment the effect of a change from a night interval of 15 hours and a day interval of 9 hours to intervals of 12½ and 11½ hours respectively was investigated with five cows. The experiment extended over nine weeks, the more unequal intervals being employed during the first two and the last three weeks [(*a*) and (*c*) in table below].

In the Cambridge experiment three cows were milked at equal intervals, and samples of their milk taken at each milking for 14 days (*a*), after which the night interval was extended to 16 hours—the day interval thus becoming 8 hours—and sampling continued for 14 days longer (*b*).

The results of the two experiments are summarised in the following table:

Experiment	Ratio Day : Night Interval	Morning		Evening		Ratio a.m. : p.m.		
		Fat %	Solids-not-Fat %	Fat %	Solids-not-Fat %	Fat %	Solids-not-Fat %	Yield
Garforth (*a*) .	1 : 1·67	2·87	9·03	4·26	9·00	1 : 1·484	1 : 0·997	1·480 : 1
,, (*b*)...	1·09	3·18	8·95	3·80	8·99	1·195	1·005	1·182
,, (*c*)...	1·67	2·94	8·83	4·40	8·79	1·497	0·995	1·382
Cambridge (*a*)	1 : 1·00	3·64	8·81	3·45	8·92	1 : 0·948	1 : 1·012	1·051 : 1
,, (*b*)	: 2·00	2·33	8·97	4·47	8·92	1·918	: 0·994	1·486

The results of the two experiments are strikingly similar in every respect, and clearly confirm the commonly accepted opinion that, apart from the influence of the individuality of the animal, the quantity and richness in fat of the milk yielded at any particular milking by a well-nourished cow in normal health are very largely determined by the length of time which has elapsed since the previous milking.

[1] Thorpe, *Journ. Chem. Soc. Trans.* 1904, 248.

The effect of the interval on the proportion of solids-not-fat is apparently not very pronounced, but it may be noted that in the two experiments mentioned the milk was in both cases richest in this respect after the longer interval, and this would indeed appear to be a fairly general rule.

Further confirmation of these conclusions is afforded by a comparison of the data obtained in the different investigations where different intervals were employed (cf. Table, p. 175). For this purpose the following table has been compiled from the available data, giving the average a.m. : p.m. ratio of the percentages of fat and solids-not-fat respectively for different degrees of inequality of the intervals between successive milkings.

Ratio Day : Night Interval	Ratio, a.m. : p.m.		Approximate No. of Samples	No. of Herds
	Fat %	Solids-not-Fat %		
1 : 1·0	1 : 1·015		400	19
		1 : 1·012	14	1
1·1	1·060		270	3
		0·998	270	3
1·3	1·157		126	3
		0·989	93	2
1·6	1·430		400	2
		0·985	300	1
2·4	1·406	0·966	30	1

It would thus appear that, in the case of herds of cows milked at equal intervals of 12 hours, the milk secreted during the day interval is only very slightly richer in fat and in solids-not-fat than that secreted during the night; but that the greater the inequality of the intervals between the milkings, the more unequal is the distribution of the fat and solids-not-fat between the two milkings, the morning milk (after the longer interval) becoming progressively poorer in fat but richer in solids-not-fat as the interval increases, whilst the quality of the evening milk varies in exactly the opposite manner.

The further question crops up in this connexion as to whether the mean results *for the whole day* are affected by the intervals between the two milkings. The only evidence available on this point from the experiments under review is that furnished by Ingle's experiment at Garforth referred to on p. 152. The mean results for the whole day in each of the three periods of the experiment are given in the following

table. The figures in brackets are the corresponding data for another group of four cows, which were milked regularly throughout the nine weeks at the more unequal intervals, and serve to indicate the allowance that must be made for the "normal" changes in the yield and quality of the milk during the periods in question.

	Ratio Day : Night Interval	Mean Daily Results		
		Yield	Fat %	Solids-not-Fat %
Period 1 (2 weeks)	1·67	164·8 (164·7)	3·43 (3·08)	9·02 (8·94)
Period 2 (4 weeks) ..	1·09	150·4 (144·1)	3·45 (3·01)	8·97 (8·80)
Period 3 (3 weeks) .	1·67	133·8 (132·1)	3·55 (3·10)	8·81 (8·77)

On comparing the records of the two groups it will be seen that the change to more equal intervals had but little effect on the mean daily yield and composition, such small difference as can be detected being in favour of the more equal intervals.

Influence of Day and Night.

Apart from the influence of the intervals between milkings, it would appear quite possible that the alternation of day and night may exert a specific influence on the milk secretion.

This is evident from an experiment carried out by Ingle at Garforth in 1900 (1 *a*). Three cows—housed day and night—were milked at intervals of six hours for four days, and samples taken at each milking. The following table gives the mean results obtained:

	Time of Milking			
	5 a.m.	11 a.m.	5 p.m.	11 p.m.
Fat %	2·8	3·6	3·5	3·0
Milk Yield (Total)...	40 lb.	23·5 lb.	24 lb.	24 lb.
,, ,, (Ratio) .	1·0	·59	·60	·60
Yield of Fat (Total)	1·1	·85	·82	·70
,, ,, (Ratio)	1·0	·77	·75	·64

In this case it is clear that the milk secreted between 5 a.m. and 5 p.m. was much richer in fat than that secreted in the night, but that

the most abundant secretion took place during the night. The experiment is not quite conclusive, however, for, as Ingle subsequently pointed out[1], "it is quite possible that the cows used had become accustomed to produce richer milk in the day-time by the long period during which they had been milked at the unequal intervals" (15, 9 hours), "and that for four days this habit still persisted."

In this connexion the results obtained in the Northumberland experiments with the Offerton herd (4 *b*) may be quoted. These cows were milked daily at 5 a.m., 1 p.m., and 6 p.m. (*i.e.*, after intervals of 11, 8, and 5 hours respectively), and the mean yield and composition of the milk obtained at each milking on the six days throughout three months on which samples were taken were as follows:

	Morning	Noon	Evening
Yield (pints)	138	79	43
Fat %..................	3·36	4·26	4·16
Solids-not-Fat % ..	8·91	9·00	9·21

It is noticeable that the yield at 5 a.m., after 11 hours' lactation, was greater than the sum of the yields at the two following milkings representing the produce of 13 hours' lactation; and further, that the percentage of fat was highest at mid-day, despite the fact that eight hours had elapsed since the morning milking, whereas the evening milking followed at an interval of five hours. Gilchrist suggests that this latter fact may have been due to less care being exercised at the 6 p.m. milking, but in view of the above and other published data precisely similar in nature[2], it is more probable that, where milking is carried out three times daily, the richest milk—in respect of fat—is usually obtained at the noon milking. The data available for solids-not-fat are insufficient to warrant any definite conclusion.

INFLUENCE OF AGE.

Information on this point is afforded by Speir's summary (9) of the results obtained during six months with 903 Ayrshire cows of approximately equal periods of lactation. The following table is abstracted from the one given in the report.

[1] *Trans. Highland & Agr. Soc.* 1903, 140.

[2] *Vide* Ingle, *Trans. Highland & Agr. Soc.* 1901, 223.

From these data it would appear that, in general, taking both yield and quality into account, there is a fairly uniform and steady improvement up to eight years of age, after which there is a gradual falling-off, which probably becomes more pronounced after the twelfth year.

Age of Cow	Number of Cows reported on	Average yield for six months	Average °/o of Fat in Milk
Years		Galls.	
2	30	362	3·83
3	147	377	3·87
4	164	403	3·76
5	137	421	3·66
6	110	438	3·63
7	88	465	3·63
8	80	468	3·69
9	50	461	3·63
10	36	457	3·64
11	28	464	3·60
12	16	493	3·48
13	10	428	3·42

The effect is more pronounced on the yield than on the fat-content of the milk, the latter showing a deterioration after the third year, which, however, is very slight, the difference between the second and tenth years amounting to no more than ·2 per cent.

There is an obvious risk in basing generalisations on results obtained with different cows in one season, but Speir expresses the opinion that "the number of animals reported on up to eight or nine years old is likely to be sufficient to neutralise the fluctuations which happen in cows of all ages, and the averages obtained may therefore be looked on as approximately correct." A few data in harmony with these generalisations are also given in connexion with the Newton Rigg herd (5)[1].

Influence of Period of Lactation.

This question is specifically discussed in only one of the reports (1 *b*), and indeed the experiments under review furnish very little reliable information on this important point, since in the great majority of cases they were carried out during the grazing season. It is well known that throughout this period the fluctuation in the quality of the milk yielded by cows is far more pronounced than when the cows are entirely restricted

In those confirmation is also afforded by the recently published results obtained by 5 p.m. wa 1904 with 302 cows (*Trans. Highland & Agric. Soc.* 1905, 194).

to the more uniform and more easily regulated conditions of the cow-house. Under grazing conditions, indeed, the normal variations in the quality of milk due to advancing lactation are frequently masked by more pronounced changes arising from causes as yet little investigated. This is especially marked in the case of the percentage of solids-not-fat, which, for example, decreases considerably during a dry summer[1], whereas under normal conditions it would probably tend rather to increase with advancing lactation (see below).

The following table has been compiled, therefore, from those experiments only in which the cows were housed for the whole or the greater portion of the day, and for which the necessary data are available (1 *a*, 3 *a*, 4 *d*, 4 *e*).

Period of Lactation. Month	No. of Cows	Average Fat %	No. of Cows	Average Solids-not-Fat %
I	8	3·78	6	8·95
II	12	3·40	7	8·72
III	10	3·35	5	8·74
IV	6	3·38	4	8·84
V	2	3·56	2	8·81
VI	4	3·86	3	9·03
VII	1	4·05	1	9·00
VIII	5	4·05	5	9·17
IX	4	4·17	4	9·10
X	2	4·27	2	9·29
XI	3	4·70	3	9·49

The number of cows included in the table is by no means large enough to ensure that the averages are not appreciably affected by the differences between individual cows of equal periods of lactation, but so far as they go they confirm clearly the view, now widely accepted, that the quality of the milk is lowest about the second or third month after calving, subsequently improving steadily with advancing lactation[2].

INFLUENCE OF SEASON OF THE YEAR.

This question is touched upon in several of the reports under review.

Thus Ingle in his 1902 report (1 *b*) compared the results obtained by him at Garforth at Easter, 1900, with those obtained there during

[1] *Vide Trans. Highland & Agric. Soc.* 1905, 326.
[2] Confirmed also by Speir, *Trans. H. A. S.* 1905, 197.

August and September of the following year. His averages are as follows:

	Fat %	Solids-not-Fat %
1900 (Mar. 22—Apr. 12)	3·86	9·06
1901 (Aug. 1—20)	3·52	8·70
,, (Aug. 20—Sept. 9)	3·55	8·70

At the same time he pointed out the possibility that the differences in composition may have been due more to differences in the food and condition of the animals than to the actual influence of the season. "It is difficult to eliminate these other influences, and therefore to determine the real character and range of purely seasonal variations."

Dymond and Bull also compared the results obtained in the two experiments carried out by them with 4—5 cows in Essex (3 *a*, *b*), and found but little difference between the mean values obtained during the winter months and those obtained during the summer months, their averages for the winter months (Nov.—Feb.) being 3·70 per cent. fat and 8·92 per cent. solids-not-fat, and for the summer months (May—Sept.) 3·83 per cent. fat and 8·83 per cent. solids-not-fat respectively. The lower percentage of solids-not-fat in the latter case is attributed to an "extraordinary falling-off" in the month of July. From the records of two cows for six months of one and the same lactation they arrived, however, at the conclusion that "during the flush of milk in the spring there is, corresponding to the increase in quantity of milk, a decrease in the proportion of fat and solids-not-fat," and subsequently an improvement in respect of both.

The evidence afforded by the Northumberland experiments (4 *b*, *c*, 5 *a*) is somewhat conflicting, as may be seen from the following data extracted from Gilchrist's report (pp. 57, 58, 61, 69).

Herd	Winter Feeding Indoors (November—April)		Pasture Feeding Outdoors (May—October)	
	Fat %	Solids-not-Fat %	Fat %	Solids-not-Fat %
Broomhaugh	3·85	8·85	3·75	8·57
Seaton Delaval	3·83	8·82	3·82	8·75
Newton Rigg (1903)	4·00	9·07	3·55	8·77

It will be noted that, whereas in the case of the Broomhaugh and Seaton Delaval herds the milk was practically as rich in fat during the summer as during the winter, it was decidedly poorer at Newton Rigg.

Gilchrist suggests that the difference may be ascribed to the fact that the cows at Newton Rigg receive no concentrated food during the first two months on pasture and only a very small quantity subsequently, but in a private communication to the writer Lawrence, of Newton Rigg, asserts that "no improvement either in quantity or quality of milk is found by giving additional food to cows when on grass up to the middle of July." No particulars are given, however, of the experiments on which this assertion is presumably based.

In all cases the percentage of solids-not-fat was decidedly lower during the summer than during the winter months.

In the case of the dairy herd at the Midland Dairy Institute (10), the average percentage of fat for the six months May—October, 1904, was 3·98, and for the remaining six months of the year 4·06—a very slight difference in favour of the winter months.

The evidence obtained in this way is thus conflicting with regard to the percentage of fat, which is obviously considerably influenced by conditions which may vary on different farms.

It may be suggested, however, that the period of six months is too long for the purpose of obtaining satisfactory evidence as to seasonal variations, and that the averages of shorter periods should, where possible, be compared. To this end the following table of monthly averages has been compiled from the available data for the mixed milk yielded in 1903 and 1904 by various herds employed in the experiments under review. For the year 1903 two complete sets of monthly averages (4 *c*, 5) are available, and for eight other herds (1 *d*, 2 *a*; 3 *a*, *b*; 4 *b*, *d*; 6 *b*; 9) the monthly averages have been calculated for periods varying from two to six months from the data given in the reports.

The figures for 1904 are compiled mainly from weekly analyses of the milk of the herd at the Midland Dairy Institute (10), other data (1 *e*, 2 *a*) being available only for the last six months. In every case, in deducing the changes from month to month, the comparison has been restricted to the records of herds for which data are given for the two consecutive months, the number of such herds being indicated in the table by the numbers enclosed in brackets. Thus the data for January and February 1903 are the averages of the records of four herds for which data obtained in these two months are available. Taking then the mean thus arrived at for February (3·65 per cent.) as the standard for this month,

the records of the four herds for which data obtained during February and March are available indicate a standard of 3·85 per cent. for the latter month. The data for subsequent months have then been deduced in similar fashion.

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	Percentage of Fat											
1903	3·90 (4)	3·65 (4)	3·85 (4)	3·75 (5)	3·65 (3)	3·75 (5)	3·80 (6)	3·75 (4)	3·90 (4)	4·35 (3)	4·40 (3)	4·75 (2)
1904	3·85 (1)	4·10 (1)	4·15 (1)	4·00 (1)	3·75 (1)	3·50 (1)	3·60 (2)	3·60 (2)	3·85 (2)	4·10 (2)	4·30 (2)	4·40 (2)
	Percentage of Solids-not-Fat											
1903	9·05 (4)	9·00 (4)	8·85 (4)	8·85 (4)	8·85 (3)	8·85 (5)	8·70 (5)	8·65 (3)	8·75 (3)	8·80 (2)	8·85 (2)	9·22 (2)
1904	—	—	—	—	—	9·12 (1)	8·99 (1)	8·80 (1)	8·65 (1)	—	—	—

The data for 1903 are probably quite reliable, since the agreement between the individual herds with respect to the direction of the changes is remarkably close.

These data point very clearly to a gradual deterioration in the average fat-content of the milk yielded by these herds during April and May in 1903, followed by a gradual improvement in respect of fat, whereas in the case of the solids-not-fat the lowest point was reached in August. Despite the paucity of data available the changes recorded during 1904 are remarkably similar in nature, the minimum percentage of fat being recorded for the month of June and of solids-not-fat for the first half of September, in each case a month later than in the previous year, the differences being probably attributable to the difference in character of the two summers. The falling-off in the percentage of solids-not-fat during the summer of 1904 was freely commented upon at the time, and generally ascribed to the prolonged drought.

It may thus be regarded as fairly probable that the average quality of milk is subject to seasonal variations, particularly during the pasturage season, the fat-content reaching its minimum generally in the months of May or June, whilst the deterioration in respect of solids-not-fat is more

prolonged, the lowest point being reached probably as a rule in July, August, or September, according to the nature of the season.

INFLUENCE OF FOOD.

Great differences of opinion with regard to this important question still exist among practical agriculturists, and hence it has received a considerable share of attention in the reports under review, many of the experiments (1 *b*, *d*, *e*, 2 *b*, 6 *a*, 7, 11) indeed having been specifically designed to ascertain definitely the nature and magnitude of this influence.

The Garforth experiments (1 *b*, *d*, *e*) are the most extensive, including as they do three distinct series of investigations carried out in different years during the months of June, July, and August, throughout which the cows were at pasture day and night. In each of the three investigations the effect of a change in the nature and albuminoid ratio of the dry food given to supplement the pasturage has been studied by comparing the average yield and quality of the milk obtained from a small group of cows during a period immediately *prior* to the change with the average yield and quality of the milk obtained from the same cows during a definite period immediately *subsequent* to the change. In order to eliminate as far as possible any disturbing effects, the data obtained with the cows under experiment have in each case been compared with those obtained with a similar group of cows (carefully selected to resemble the test-group as closely as possible), which received the same diet throughout the whole experiment. Throughout the investigations the milk of each individual cow was sampled at each milking.

In the experiment carried out in 1901 (1 *b*) the 19 cows included were fed uniformly for several weeks prior to and throughout the first 20 days of the experiment (Control Period), each receiving as dry food 2 lbs. decorticated cotton cake daily. After the twentieth day the cows were divided into four groups, one group (the control group) continuing to receive the same food, a second receiving daily 4 lbs. of gluten meal, a third 6 lbs. of maize meal, and the fourth 28 lbs. of fresh brewers' grains, instead of the decorticated cotton cake. The experiment was continued for 20 days after the change of food (Test Period).

The following table, modified from the original, gives the averages for the second period for each group, recalculated on the assumption

that in the first period each had given mean results identical in every respect with those of the control group.

	No. of Cows	Yield, lbs.	Fat %	Solids-not-Fat %
Control Period (20 days), (all groups)		114·4	3·38	8·55
Test Period (20 days):				
Cotton Cake (Control Cows) .	5	103·6	3·48	8·59
Gluten Meal......	5	107·9	3·52	8·67
Maize Meal	5	107·0	3·30	8·56
Brewers' Grains	4	100·7	3·46	8·55

From these figures it is obvious that the changes produced were small in every case, and possibly the differences indicated were within the limits of experimental error. In this connexion Ingle remarks that "it must be remembered that the figures are deduced from the differences between the means of two sets of analyses, each set containing 40 independent values for the milk of each cow. That the changes were in the direction indicated, therefore, I think we may feel tolerably certain, but any conclusions that we draw from this investigation as to the influence of food must be applied only to similar cases."

Assuming the figures to be reliable to the extent suggested, it would appear that the best results were yielded by the gluten meal—a typical highly nitrogenous food—and the worst, so far as the quality of the milk is concerned, by the maize, a food relatively poor in albuminoids. The data referring to brewers' grains are not of special interest, since "the feeding of grains to cows at pasture is an unusual practice." Attention may simply be directed to the fact that, "contrary to what was expected," this group of cows showed relatively the greatest *diminution* in yield.

"Another important question upon which this investigation fails to throw any light is, whether the changes in milk produced by change of food are only temporary or last for any appreciable time. It seems highly probable that the mere fact of changing the food may stimulate the vital processes of the animals and so alter their milk, but that, when this stimulus has disappeared, the old order of things may be restored and the milk may return to its normal condition." (Ingle.)

In view of this uncertainty and the great importance of the question, further experiments on similar lines were carried out at Garforth by the

writer in the summers of 1903 and 1904 (1 *d*, *e*). In the former year the effects of a replacement of 2 lbs. decorticated cotton-seed meal and 1 lb. wheat meal by 3 lbs. of maize meal was studied with a group of five cows for five weeks after the change of food, in order to test more thoroughly the degree of permanency of any changes recorded.

In the latter year the effects of change of food were studied with a group of seven cows, but for 19 days only, in connexion with a more extensive investigation. In this year the change of food investigated consisted in the replacement of 3 lbs. decorticated cotton cake by 3 lbs. maize meal.

The cows were at pasture day and night throughout each experiment, and the method of procedure was precisely that of the 1901 experiments outlined above.

The results are summarised in the following table, drawn up in precisely similar fashion to the preceding one (p. 162).

	No. of Cows	Mean Daily Yield, lbs.	Fat %	Solids-not-Fat %
1903				
Control Period (17 days), (all Cows) ...		108·0	3·27	8·74
Test Period (52 days):				
First 3 weeks—				
Cotton-seed Meal (Control Cows)	5	91·5	3·40	8·50
Maize Meal..........................	5	98·8	3·31	8·49
Last 2 weeks—				
Cotton-seed Meal (Control Cows)	...	79·5	3·60	8·52
Maize Meal	...	87·7	3·41	8·62
1904				
Control Period (28 days), (all Cows)...		213·6	3·36	8·88
Test Period (19 days):				
Decort. Cotton Cake (Control Cows)	7	190·6	3·50	8·82
Maize Meal	7	185·9	3·41	8·74

So far as the quality of the milk is concerned, it will be noted that the results closely confirm those obtained in the previous experiment, in that slightly richer milk was obtained with the more nitrogenous food, the only exception being in the case of the solids-not-fat for the last two weeks of the test period in the 1903 experiment. From the respective data given for the first three and last two weeks of the test period in this experiment it would appear as if the influence of the change of food had remained unabated throughout the whole period, but in the 1904

experiment the changes produced were apparently far more temporary in character, as is evident from the weekly averages given in the report[1]. The experiments are thus indecisive with regard to this point.

The fact must not be overlooked that there is considerable possibility of error in the assumption underlying these methods of investigation that any deviations in the case of the test group from the magnitude and direction of the fluctuations recorded by the control group are to be attributed to the changes investigated. This possibility is of course less the greater the number of cows experimented with, and in this connexion it is perhaps significant that the smallest effects were recorded in the series of experiments with the largest groups, viz., in 1904.

It must further be admitted that the conditions at Garforth are in some respects ill adapted for experiments of this nature, the marked inequality of the intervals between milkings conducing to greater fluctuations in the quality of the milk, and consequently a higher probable error of the mean results than would be the case if milking were carried out at equal intervals.

The close agreement between the results obtained in different years is, however, presumptive evidence that the experiments were at least precise enough to indicate the direction, if not the magnitude, of the changes effected.

An experiment on similar lines (7) was also carried out with six cows by Atkinson at Wye in the last three months of 1901, with the object of comparing the effect of additions of a highly nitrogenous food —linseed cake—and a typically starchy food—maize meal—respectively to a ration of average albuminoid-content but rather low in quantity. The experiment was continued for two months after the change of ration, and the conclusion arrived at as to the effects of the changes investigated was that, "taking the results generally, it appears that neither the change from a low diet in point of quantity to a higher one, nor the change from a medium diet in respect of albuminoids to a more or less nitrogenous one, affected the amount of butter-fat given to any appreciable extent....As far as these experiments go, they tend to support the view that the amount of butter-fat a cow gives is not materially dependent upon the nature of her food, but is governed by other causes, such as the period of lactation, and each cow's peculiar aptitude to produce richer or poorer milk." Possibly if a larger number of cows could have been employed for the experiment, slight differences such as those observed at Garforth might have been detected.

[1] *Highland & Agric. Soc. Trans.* 1905, 331, 332.

Similar conclusions were arrived at in the experiments carried out in connexion with Reading College in Jan.—March, 1902 (6 *a*), in which three different rations were tested with three lots of four cows each, and also in the comparison of the feeding value of different varieties of mangels carried out with eight cows in 1903 (6 *b*).

In the experiment carried out at the Harper Adams College in 1904 (2 *b*), decorticated cotton cake (6 lbs.) and maize (8 lbs.) in quantities representing equal money values were compared with two lots of three cows each. The results indicated a slight advantage in favour of the cotton cake in respect both of yield and quality.

In Robb's experiments (11), in which four groups of six cows each were employed, the feeding value of gluten feed was compared with that of a mixture of bean meal and crushed oats on the one hand, and a mixture of maize meal and decorticated cotton cake meal on the other hand. A further comparison was also effected of the relative feeding values of equal weights of sugar beets and turnips. Although there were in some cases marked differences in the effects of the different rations on the yield of milk—notably the relative inferiority of the ration comprising maize and cotton cake meal—the proportion of fat and solids-not-fat in the milk was apparently in no case appreciably affected.

The influence of food on the milk-secretion has also been touched upon in the reports of other experiments not specially designed for the investigation of this point (3 *a*, 4 *d*), and in each case the opinion has been formed that changes of food have little if any effect on the milk.

These experiments—carried out under summer and winter conditions, in widely different parts of the country—are thus unanimous in indicating that such changes as may possibly be effected in the quantitative composition of milk by change of food are only very slight, provided, of course, the rations prior and subsequent to the change are suitable in nature and in quantity.

Very few observations have apparently been made in the course of these experiments as to the influence of food on the *qualitative* composition of milk, although there is every reason to believe that the effects are most pronounced in this respect. Thus Robb reports decided differences in the churnability of the cream and on the flavour and quality of the butter produced from the milk of cows receiving different foods.

Influence of Manner of Feeding.

Experiments have been carried out at Garforth in the years 1902–4 (1 *c*, *d*, *e*) with the object of investigating the possibility of periodically stimulating the production of fat by feeding cows at stated times with rich food, given to supplement pasturage.

The method of investigation adopted (Ingle, 1902)—after an unsuccessful attempt to ascertain the interval between feeding and its effect upon the milk by the admixture of colouring matters with the food—consisted in comparing the records of three groups of four cows each for a period of five weeks, one group (control cows) receiving its dry food in two equal portions, morning and night—the customary manner of feeding at Garforth, and adopted with all the cows during the immediately preceding (control) period—a second receiving its dry food in the morning only, and the third receiving its dry food at night; the total weight of food supplied per day being the same in each case.

The experiments were repeated by the writer in 1903 and 1904 on precisely similar lines, save that in the latter year the effect of exclusively evening feeding was not investigated.

The results of the three series of experiments are summarised in the following table (p. 167), containing data modified somewhat from those given in the original reports in that, to facilitate comparison, the assumption has been made that the average fat-content during the period of normal feeding (dry food given in two equal portions) was 3 per cent. in each case, and the data obtained in other periods correspondingly modified, due attention being paid to the normal fluctuations as measured by the control group.

If this method of analysing the experimental data may be trusted there would appear to have been a decided difference in favour of the more intermittent mode of feeding. It may be noted, however, that the apparent effect was far less pronounced in the two latter years than in 1902, and moreover that, whether the food was given all in the morning or all at night, the apparent effects were not confined to the one or the other milking. The ratio between the percentages of fat in the morning and evening milk respectively was indeed narrowed somewhat by the more intermittent feeding in some of the experiments —notably in the 1902 experiments—but not in all.

Here again, as in the investigations into the influence of change of food (*vide* p. 164), it is significant to note that the least effects were recorded in the experiment in which the groups were largest.

Year of Experiment	No. of Cows in Group	Morning Milk — Dry Food given: In two equal portions	Morning Milk — Dry Food given: All in Morning	Morning Milk — Dry Food given: All at Night	Evening Milk — Dry Food given: In two equal portions	Evening Milk — Dry Food given: All in Morning	Evening Milk — Dry Food given: All at night
		%	%	%	%	%	%
1902	4	3·00	3·53	3·41	3·00	3·28	3·27
1903	4	3·00	3·12	3·17	3·00	3·14	2·97
1904*	7	3 00	3·05	—	3·00	2·95	—
Mean .	....	3·00	3·21	3·03	3·00	3·11	3·12

* The 1904 experiment was but part of a more comprehensive experiment in which the writer endeavoured to determine the effect on the milk of a group of 7 cows of a simultaneous change in the nature of the stall food and the mode of feeding—full details of which are given in the report (*Highland and Agr. Soc. Trans.* 1905). No very definite effect could be detected beyond the slight disturbance immediately subsequent to the sudden introduction of the changes, this being, so long as it lasted, precisely similar in nature to the changes observed under similar conditions in previous years.

Further investigation of the question is desirable, but from these experiments it appears not improbable that some change, perhaps only very slight, may be effected in the quality of milk by changes in the manner of feeding such as those referred to above.

INFLUENCE OF WEATHER.

Apparently very little reliable evidence is available with respect to the influence on the milk-secretion of fluctuations of temperature and weather conditions generally to which cows are subjected.

The problem is touched upon and to some extent discussed in some of the reports under review, but in no case has it been really satisfactorily dealt with.

It is not to be wondered at, therefore, that diametrically opposite conclusions have been arrived at by different investigators. Thus Dymond and Bull (3 *a*) report that "the temperature out of doors has had extraordinarily little effect on either milk-yield or quality.... The only marked change was observed when the temperature of the cowhouse fell below 50°," which caused a falling-off in yield, "but it did not appreciably affect the percentage of fat or solids." A similar conclusion is again arrived at in the recently issued report of the

committee (Messrs Dyer, Dymond and Thresh) appointed by the Essex County Council to investigate this question. This report is based on a careful comparison, month by month, of the rainfall records with the average quality of milk in Essex during each month of the past three years, as indicated by the results of analyses of nearly 1200 samples taken within the county under the Sale of Food and Drugs Act. Similarly, Ingle in his first report (1 *a*) states that no distinct influence of change of temperature (of the cowhouse) upon the composition of the milk could be traced.

On the other hand, Gilchrist, in his summary of the results of the experiments carried out under his direction in Northumberland (4 *b*–*f*), remarks that "the weather conditions have evidently a very important influence on milk production. This is especially noticeable in the Seaton Delaval results, where cold north and north-east winds have considerably lowered the fat-contents of the milk. The milk of one cow at Cockle Park has been reduced in percentage of fat by cold nights in June and by hot days in July. Wilson has also found at Stockton-on-Tees that severe weather has reduced the amount of fat. It is therefore advisable to guard against exposing cows unduly to either severe or hot weather, and especially to great variations in temperature."

Again, Ingle in his second paper (1 *b*) instances one "cool, dull day following several exceedingly hot ones," on which "the separate (evening) milk of almost all the cows was of unusually high quality." This phenomenon was also noted several times by the writer during his investigations in 1903.

Atkinson, in his report on the feeding experiment carried out by him at Wye (7), suggests that the "very marked drop" in the fat-content of the milk of each cow during the third week of the experiment was probably due to the "very raw, foggy weather" that prevailed.

It should be noted, however, that in most cases where an attempt has been made to arrive at the influence, if any, of variations of weather on the milk-secretion, the attention has been mainly concentrated on the fluctuations in quantity and quality of the *mixed milk* of herds. It is doubtful whether much reliable information may be obtained in this way. The effect, if any, will be exerted on the milk-secretion through the nervous organisation of the cow, and it is well known that there are very great differences in nervous temperament between individual cows. It is practically certain, therefore, that the magnitude of the effects produced on the milk-secretion by changes of weather will vary considerably with different cows, and it is quite possible that there may even be

differences in the nature of the changes in the case of different cows. More reliable information may therefore be expected from a comparison of the meteorological data with the records of individual cows, and particularly such as are notably of highly nervous temperament.

An attempt was made by the writer, in connexion with the experiments carried out at Garforth in 1903, to effect roughly such a comparison, the results of which are fully discussed in the report (1*d*). A table was constructed, recording for each of the 52 days on which samples were taken the respective numbers of cows giving milk either decidedly above or below the average for the particular period of the experiment in which each day occurred, and the data thus obtained were compared with the daily fluctuations in the general weather conditions. From this comparison a far greater degree of regularity between the climatic changes and the fluctuations in the quality of the milk yielded by the cows was traceable than could be seen from the data for the mixed milk. The connexion was still, however, not sufficiently exactly defined to admit of absolutely trustworthy conclusions being arrived at, but certain opinions were expressed which received considerable support from the experimental data. These opinions were to the effect that, with most of the cows during pasturage,

(*a*) Change from an equable to either a decidedly low or a decidedly high temperature tended at first to produce a secretion of milk poorer in fat.

(*b*) The first effect of a fall of rain would appear to have been to cause secretion of richer milk, this being especially noticeable in the morning milk after wet nights[1].

(*c*) The influences were only of a very temporary nature, the return to normal conditions being fairly rapid with a continuance of fairly uniform climatic conditions.

These opinions were given, however, with all reserve, being based on observations extending over a very limited period. It is hoped that more reliable information will accrue from the further comparison of the analytical data accumulated at Garforth with the more precise expression of the climatic changes afforded by the meteorological records.

[1] It is possible of course that the effects ascribed to the weather conditions may in many cases arise only indirectly therefrom. Thus rain after drought will considerably affect the succulence of the herbage and may thereby produce an effect on the milk-secretion.

Comparison of Night Pasturage with Housing of Milking Cows in Autumn.

This important practical question has been the subject of experiment during the last four winters at the Harper-Adams Agricultural College.

In each year 10 cows have been selected, carefully arranged in two equal groups, and treated exactly alike except that, whereas one group remained at pasture day and night, the other group were housed from the evening milking of one day to the close of the following morning milking, receiving a quantity of hay in the racks to compensate for the removal from pasture. The experiments covered the months of October to December, and the comparison of the two systems was based on analyses of composite samples of the morning and evening milk taken frequently before and after the commencement of the experiment.

The results are striking, being quite contrary to general opinion in that they reveal no advantage accruing from the night housing, neither in respect of yield nor quality of the milk, but rather the reverse. In nearly every case the milk yield fell off less rapidly and the fat-content of the milk increased more rapidly in the case of the cows which remained at pasture through the night than in the case of the cows passing the night in the cowhouse. Moreover the former invariably showed a greater increase in live weight than the latter, indicating that, to say the least, they did not suffer by the treatment.

This result is so remarkable and contrary to general expectation, and of such practical importance, that independent confirmation is highly desirable.

A certain degree of confirmation is afforded by a small experiment carried out on similar lines—in ignorance of the Harper-Adams experiments—by the writer at Garforth during the last few days of August and the first half of September, 1904. Four cows, which for several months previously had been at pasture day and night, were housed at night during this period, receiving hay *ad lib.* in the stalls. Their records have been compared with those of a similar group of cows which were at pasture day and night, and have proved to be practically identical. It may be objected that the period at which this experiment was carried out was unduly early, and indeed it was intended to be only preliminary to a more thorough investigation. Still if there be, in general, any marked difference in the effects of the two modes of treatment of the cows, surely this would have been evident to some extent in the results.

INFLUENCE OF SEXUAL EXCITEMENT.

This question is referred to in several of the reports (1 *b*, *d*, 3 *b*, 4 *e*, *f*), the data accumulated affording many instances of remarkable fluctuations in the amount and quality of the milk yielded by cows when under this influence.

In every case it is noted that the magnitude of the influence varies enormously with different cows, being indeed in many cases quite inappreciable. Moreover, even in those cases where the milk-secretion is undoubtedly affected, there is apparently no absolute regularity in the effects produced, nor in the period throughout which the effects are evident.

In most cases the milk obtained at the first milking after the outward manifestation of sexual excitement is abnormally low in quantity and poor in fat—the proportion of solids-not-fat remaining practically unaffected, whilst at the following milking an unusually high yield of milk rich in fat is generally recorded. These fluctuations in some of the recorded cases amount to as much as 300 or 400 per cent. of the lower values.

Numerous instances of such fluctuations were recorded by the writer in 1903 (1 *d*) in connexion with the cows of the Garforth herd. From the comparison of these data the opinion was expressed that the influence is inappreciable after two or three milkings subsequent to the cow coming in "season."

Attention was also directed to the fact—noted also in the report of the Northumberland experiments (4)—that in many cases the fat-content of the milk was decidedly above the average on the two or three days immediately preceding the period of active sexual excitement.

COMPOSITION OF MILK FROM SEPARATE PORTIONS OF THE UDDER.

An interesting series of analyses of the milk drawn from each separate quarter of the udders of several cows was published by Ingle in his report on investigations carried out by him in the summer of 1902 (1 *c*).

Samples were taken twice daily for six days from two cows, and on analysis revealed very striking differences in composition, especially in respect of solids-not-fat. In the case of both animals the lowest proportion of solids-not-fat was invariably found in the milk from the same quarter—the left fore teat—and in every case the quantity of milk

yielded by this quarter was much less than that from the other quarters of the same cow.

In order to test the generality of this phenomenon a set of four samples was taken from each of the 19 cows in the herd. Of these, 10 gave distinct indications that the left fore-quarter gave milk less in quantity and poorer in solids-not-fat than any of the other three quarters, the means for these 10 animals being:

	Fat %	Solids-not-Fat %	Milk Yield, lbs.
Right fore-quarter	3·93	8·71	2·73
Right hind-quarter......	4·24	8·70	3·25
Left fore-quarter.........	3·87	8·18	1·83
Left hind-quarter	4·02	8·70	2·82

Of the remaining nine animals, three yielded milk poorest in solids-not-fat from the right hind-quarter, whilst the other six cows gave results which were not conclusive.

These differences were apparently, however, not permanently characteristic, for when after an interval of four or five weeks further samples were drawn from one of the two cows whose milk was first sampled, it was found that the left *hind*-quarter was now the one giving milk poorest in solids-not-fat, and this was still the case some nine or ten weeks later. With these later samples direct determinations of albuminoids and sugar were made, and it was found that the poverty in solids-not-fat of the milk from the left hind-quarter was attributable to the low proportion of sugar.

Ingle, in conclusion, remarks that "the variation in fat in milk from different quarters of the udder is perhaps not surprising when we remember that the fat is apparently produced by the breaking-down of fat-cells in the gland itself; but that different glands, or different parts of the same gland, should be able to elaborate from the same blood supply products of different concentration in dissolved matter, appears to the writer to be very remarkable."

Average Composition of Milk.

The investigations under review comprise in all about 50 different herds ranging in size from 3 to 61 cows, and located in widely different parts of the country. They furnish therefore a considerable

amount of evidence concerning the average quality of milk as obtained in this country, and it is of interest to compare the different records.

The following table has therefore been drawn up from the data, relative to the mixed milk of the herds, furnished by each report; such data being in many cases based on analyses of actual samples of the mixed milk, and in others arrived at by calculation from the results of analyses of the samples of the milk of each individual cow.

Experiment	No. of Herds	Average No. of Cows per Herd (approx.)	Morning			Evening			All Samples		
			No. of Samples (approximate)	Fat %	Solids-not-Fat %	No. of Samples (approximate)	Fat %	Solids-not-Fat %	No. of Samples (approximate)	Fat %	Solids not-Fat %
1	1	18	366	2·91	8·90	364	4·20	8·84	730	3·56	8·87
2	1	8	—	—	—	—	—	—	75	3·81	—
3	1	5	173	3·62	8·84	173	3·84	8·93	346	3·73	8·89
4	5	11	162	3·48	8·80	162	4·13	8·65	324	3·81	8·73
5	1	17	12	3·63	9·00	12	3·83	8·84	24	3·73	8·92
6	2	10	45	2·89	—	45	3·71	—	90	3·30	—
7	1	6	—	—	—	—	—	—	120	3·25	—
8	1	3	28	2·99	8·89	28	3·96	8·92	56	3·48	8·90
9	19*	40	190	3·77	—	190	3·85	—	380	3·81	—
	34*	39	—	—	—	—	—	—	450	3·68	—
10	1	28	33	3·49	—	33	4·08	—	66	3·79	—
11	1	24	70	3·16	8·47	70	3·42	8·47	140	3·28	8·47
Total	49	—	1080	3·60†		1080	3·90†		2800	3·70†	
			710		8·81†	710		8·74†	1420		8·78†

* In the case of nineteen of the thirty-four heads tested in this experiment, samples of the mixed milk at each milking were tested in addition to samples from each individual cow.

† Average per herd.

It will be observed that the averages deduced from all samples agree very closely with the well-known averages of the Aylesbury Dairy Company, which are so commonly accepted as representative of the average quality of milk as supplied in this country.

The quality of individual samples frequently deviated considerably from these means, however, as may be seen from the following table, in which are given the extreme limits of variation recorded in the case of the mixed milk of each herd (of five or more cows) for which data are available.

LIMITS OF VARIATION IN QUALITY OF MIXED MILK OF HERDS.

Experiment	Fat		Solids-not-Fat	
	Minimum %	Maximum %	Minimum %	Maximum %
1 *a*	2·9	5·0	8·6	9·5
1 *b*	2·0	4·8	—	—
1 *c*	2·2	5·3	8·6	9·2
1 *d*	2·55	5·25	8·4	9·4
1 *e*	2·55	5·1	8·45	9·35
3 *a*	3·04	4·36	8·6	9·45
3 *b*	3·12	4·87	8·6	9·3
4 *b*	3·03	4·53	8·75	9·45
4 *c*	2·8	4·6	8·4	9·3
4 *d*	3·3	4·6	8·55	8·9
5..	3·0	4·4	8·55	9·35
6 *a*	3·25	4·05	—	—
10...	3·0	4·7	—	—
All Experiments ...	2·0	5·3	8·4	9·5

The range of variations is, of course, still greater in the case of samples drawn from the milk of individual cows, but in no case are values recorded outside the limits—Fat 1·04—12·52 per cent.; Solids-not-Fat 4·90—10·60 per cent.—quoted by Richmond[1].

In conclusion, the writer would take this further opportunity of expressing his indebtedness to the various investigators whose work has been touched upon in this *résumé*, for generous responses to requests for more detailed information in connection with their experiments.

[1] *Dairy Chemistry*, p. 120.

LIST OF INVESTIGATIONS UNDER REVIEW.

No.	Investigations in connexion with	Year	Commenced on	Period covered by Investigations	Number of Cows	Ratio of Intervals between Milkings. Day Interval : Night Interval	Frequency of Sampling	Details of Publication of Results
1 *a*	University of Leeds (Garforth Experimental Farm)	1900	22. iii.	Days 21 4	17 4	1 : 1·6 : 1 : 1 : 1	Twice daily 4 times ,,	Ingle, *Highland & Agric. Soc. Trans.* 1901, XIII. 218
1 *b*	,, ,, ,, ,, ,, ..	1901	1. viii.	40	19	1·6	Twice daily	,, ,, ,, ,, 1902, XIV. 284
1 *c*	,, ,, ,, ,, ,, ...	1902	25. v.	63	17	,,	,, ,,	,, ,, ,, ,, 1903, XV. 135
1 *d*	,, ,, ,, ,, ,, .	1903	10. vi.	52	18	,,	,, ,,	Crowther, ,, ,, ,, 1904, XVI. 268
1 *e*	,, ,, ,, ,, ,, ...	1904	7. vi.	95	14	,,	,, ,,	,, ,, ,, ,, 1905, XVII. 296
2 *a*	Harper-Adams Agricultural College	1901	2. xi.	35	10	1·5	1 day weekly	*Report for Season* 1904, p. 13
		1902	22. xi.	21	,,	,,	,, ,,	
		1903	31. x.	28	,,	,,	,, ,,	
		1904	5. xi.	56	,,	,,	,, ,,	
2 *b*	,, ,, ,, ,, ...	1904	—	42	6	—	—	Private communication from Mr Foulkes
3 *a*	Essex Education Committee	1902	18. xi.	103	4	1·1	Twice daily	Dymond and Bull, *Special Pamphlet*
3 *b*	,, ,, ,, ...	1903	11. v.	140	4—5	,,	Twice daily for five separate fortnights	,, ,, ,, ,,
4 *a*	Armstrong College, Newcastle-on-Tyne	1902	1. x.	—	18	2·4	Twice daily	Collins, *Journ. Soc. Chem. Ind.* 1902, XXI. 1512
4 *b*	,, ,, ,, (Offerton Herd)....	1903	10. i.	71	12	1·6 : 2·2	1 day fortnightly	*Twelfth Annual Report on Experiments*, 1903, 54 (Durham College of Science)
4 *c*	,, ,, ,, (Broomhaugh Herd)	,,	14. i.	336	12	1·3	,,	,, ,, ,, ,, ,, 57
4 *d*	,, ,, ,, (Seaton Delaval Herd)	,,	4. iii.	40	6	1·3	Twice daily	,, ,, ,, ,, ,, 59
4 *e*	,, ,, ,, (Alnwick Herd)	,,	19. iii.	33	3	1	,, ,,	,, ,, ,, ,, ,, 64
4 *f*	,, ,, ,, (Cockle Park).... ...	,,	1. i. 19. v.	113 165	1 1	1·2–2 1·1–2	,, ,, ,, ,,	,, ,, ,, ,, ,, 67 ,, ,, ,, ,, ,, 68
5	Cumberland and Westmoreland Farm School (Newton Rigg)..	,,	15. xii. '02	335	17	1·1	1 day monthly	,, ,, ,, ,, ,, 69
6 *a*	University College, Reading......	1902	5. i.	84	12	—	,, ,,	Percival, *Journ. Board of Agric.* 1903, IX. 51
6 *b*	,, ,, ,, ...	1903	10. iii.	42	8	1·7	Twice daily	,, *Ninth Annual Report on Experiments*, 1903, 5
7	South-Eastern Agricultural College, Wye	1901	20. x.	64	6	1·4	,, ,,	Atkinson, *Journ. S.-E. Agric. College*, No. 11, Feb. 1902
8	Cambridge University	1903	12. v.	28	3	1, 2	,, ,,	Rudge, *Fifth Annual Report on Experiments*, 1903, p. 92
9	Highland and Agricultural Society	,,	11. v.	180	1342	1	1 day fortnightly	Speir, *Highland & Agric. Soc. Trans.*, 1904, XVI. 170
10	Midland Dairy Institute	1904	1. i.	365	26	1·3	1 day weekly	Private communication from Mr Golding
11	West of Scotland Agricultural College	1903	11. ii.	70	24	1·1	Twice daily	D. K. Robb, *West of Scotland Agric. Coll. Bull.*, No. 29

VARIATION IN THE CHEMICAL COMPOSITION OF MANGELS.

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THE investigations described in the following pages are the outcome of a series of experiments started in the spring of 1902, on the University Farm, and on three farms in the county of Norfolk. The Norfolk Chamber of Agriculture, after investigating the manuring of root crops in 1886 and succeeding years[1], and the utilisation of root crops for feeding sheep and cattle during the nineties[2], turned its attention in 1900 to the investigation of the quality of the root crop. During 1900 and 1901 a feeding experiment was carried out with swedes grown with various manures, and both the analyses of the roots and their effect on the cattle[3] showed that the feeding value of the roots was affected by manuring to an almost inappreciable extent. It was therefore proposed to the Chamber that, before any further feeding experiments (which are lengthy, costly, and extremely difficult to carry out satisfactorily) were organised, an extended investigation in the field and in the laboratory should be carried out, in order to determine the extent of variation in quality of which root crops were susceptible. The experiments were therefore started on the University Farm in the spring of 1902, with the co-operation of the Chamber, who arranged to grow material on three farms in Norfolk, and have been continued in the two succeeding seasons. They have been extended since the first year by the co-operation of the Bedford County Institute at Ridgmont, which grew material in 1903 and

[1] *Annual Reports of the Norfolk Chamber of Agriculture.*
[2] *Ibid.*, and *Journal of the Board of Agriculture*, 1899, VI. p. 311.
[3] *4th Annual Report Camb. Univ. Dept. of Agric.* 1901–2, p. 73.

1904, and of the County Councils of Essex and West Suffolk in 1904. Short preliminary notes on the progress of the work have already been published[1], and now, after three years' work, and the examination of 600 large mixed samples and over 1000 individual roots, we are in a position to state certain definite conclusions with regard to mangels. A large amount of work has also been done on swedes, turnips, and kohl rabi, but the results are not at present sufficiently definite for publication.

But little information as to the variation in the composition of roots can be found in modern standard works on agricultural chemistry. Wolff[2] gives 12 per cent. as the average content of dry matter in mangels, and makes no suggestion as to variability; Warington[3] states that small roots (mangels) contain on the average 13 per cent., and large roots only 11 per cent. of dry matter; and Stephens[4] gives 12·2 per cent. as the average content of dry matter, but adds that it may vary from as little as 10 per cent. in wet seasons to as much as 16 per cent. in dry seasons, and he too notes that small and medium-sized roots contain more dry matter than large ones.

That very considerable variation does occur beyond that due to soil and season is seen at once on consulting periodical literature. A. Voelcker[5] gives analyses of nine single roots of the Orange Globe mangel, each from a differently manured plot, in which variations are shown in dry matter from 7·4 to 10·5 per cent., in sugar from 2·3 to 5·6 per cent., and in nitrogen from ·17 to ·26 per cent.

Anderson's[6] analyses of three varieties show very considerable variation in composition. Thus the percentage of dry matter varies from 9·44 in Long Red and 9·76 in Yellow Globe to 11·57 in Long Yellow. He also points out that care in sampling roots is necessary, as the composition varies in different parts of the root.

A later paper[7] by the same author, this time on swedes, is of considerable interest. It gives in parallel columns analyses of 20 individual roots, their specific gravity, and the specific gravity of their juice. The analyses were made to test the soundness of a method of selection practised at that time by the then Marquis of Tweeddale, which

[1] *Proc. Camb. Phil. Soc.* 1903, XII. 2. 97; *5th Annual Report Camb. Univ. Dept. of Agr.* 1903; *Report of Brit. Assoc. Agric. Sub-Sec.* 1904.

[2] "Farm Foods," *Cousins' Trans.* p. 306.

[3] *Chemistry of the Farm*, 1902 ed., p. 130.

[4] *Book of the Farm*, 4th ed. I. 265.

[5] *R.A.S.E. Journal* 1866, II. 2. p. 201.

[6] *Highland Soc. Trans.* 1853–5, p. 274.

[7] *Highland Soc. Trans.* 1855–7, p. 183.

consisted in growing on for seed the roots of highest specific gravity. Anderson's figures show that very great variation occurs in the composition of the individual roots, and in the specific gravity of both root and juice, but that the specific gravity of the root indicates rather the amount of included air than the composition of the root. He considers that the specific gravity of the juice is a surer indication of high percentage of dry matter, but his figures do not seem to bear out this conclusion. Cp. p. 206.

Wilson[1] quotes figures showing that considerable variation occurs between different varieties, Long Red containing only 1·60 per cent. of nitrogenous compounds, as against 2·12 per cent. in Red Globe.

Many analyses of mangels have been made on the Continent and in America[2]; these show great variation in composition, but we have not been able to find the data as to variety, season, manurial treatment, and cultural conditions, to enable us to decide as to the causes of variation.

The Rothamsted figures[3] show seasonal variation in mangels grown without manure from 12·18 per cent. dry matter in 1895, to 18·94 per cent. in 1887, and a difference of 3·2 per cent. on the average of 25 years between mangels grown without manure and with complete artificials.

It is evident therefore, from perusal of the literature quoted above, that mangels are subject to great variation in chemical composition, and that this variation is due to a number of causes, among which may be mentioned individuality, size of root, strain, season, and manuring.

Method of Experimenting.

The method adopted in carrying out the investigation has been to sow annually at several stations a number of seedsmen's strains of swedes, mangels, and turnips. These were sown on plots side by side, and treated similarly in every possible way, both culturally and manurially. In the autumn the crop of each plot was weighed if possible, sampled, and analysed.

Comparison of the figures gives information as to the variation among the different strains on different soils, and comparison of the figures for the three years gives some idea of seasonal variation.

[1] *Our Farm Crops*, I. p. 450, Edinburgh, 1859.

[2] *Jahresbericht über Agric. Chemie*, 1880 to 1890.

[3] *Annual Memoranda*, 1901.

Other plots were grown with the same strain differently manured, analyses of samples of which gave information as to the variation caused by manuring.

Large numbers of individual roots of several strains were weighed, sampled, and analysed, to obtain information as to variation with size and individuality.

Anderson's work, quoted above, calls attention to the uneven distribution of certain constituents throughout the root. This question has been more fully investigated, and information obtained as to the distribution of dry matter, sugar, and nitrogen through the root, and a method of sampling devised to meet the case.

SAMPLING.

In deciding on a method of sampling a crop of roots, two points have to be taken into consideration, firstly how to obtain a small portion which shall fairly represent the composition of one individual root, and secondly how many individual roots must be so sampled in order to obtain a representative sample of the whole crop.

For sampling individual roots two methods have been used. One of them consists simply in cutting out a vertical sector from the root, and reducing this to pulp by some kind of rasp. This method necessitates the manipulation of large quantities of material, and is therefore cumbrous where large numbers of samples have to be collected from considerable distances. We therefore inclined to the other method, which is essentially the removal from the root of a core by means of an instrument like a cheese-borer. Such cores are rapidly taken, and pack easily for carriage to a distance.

Removal of a core does not damage the root for seed-growing; in fact, coring is the method adopted for sampling sugar-beet for the chemical selection of roots for seed-mothers, and has been used with such marked success that the method may be taken as reliable. It has also been used by Collins[1] in his work on swedes.

During our first year's work we tested the method carefully by determining the percentages of dry matter in 100 individual roots, each of which was first cored and then divided into vertical sectors. The core was dried to constant weight, and side by side with it one of the sectors representing as nearly as possible one quarter of the root. The

[1] *10th Annual Report Durham College of Science*, 1901.

means of the two series of determinations differed by less than ·1 per cent., thus:

Mean of 100 determinations by the coring method, 12·81 per cent.
" " " " sector " 12·76 "

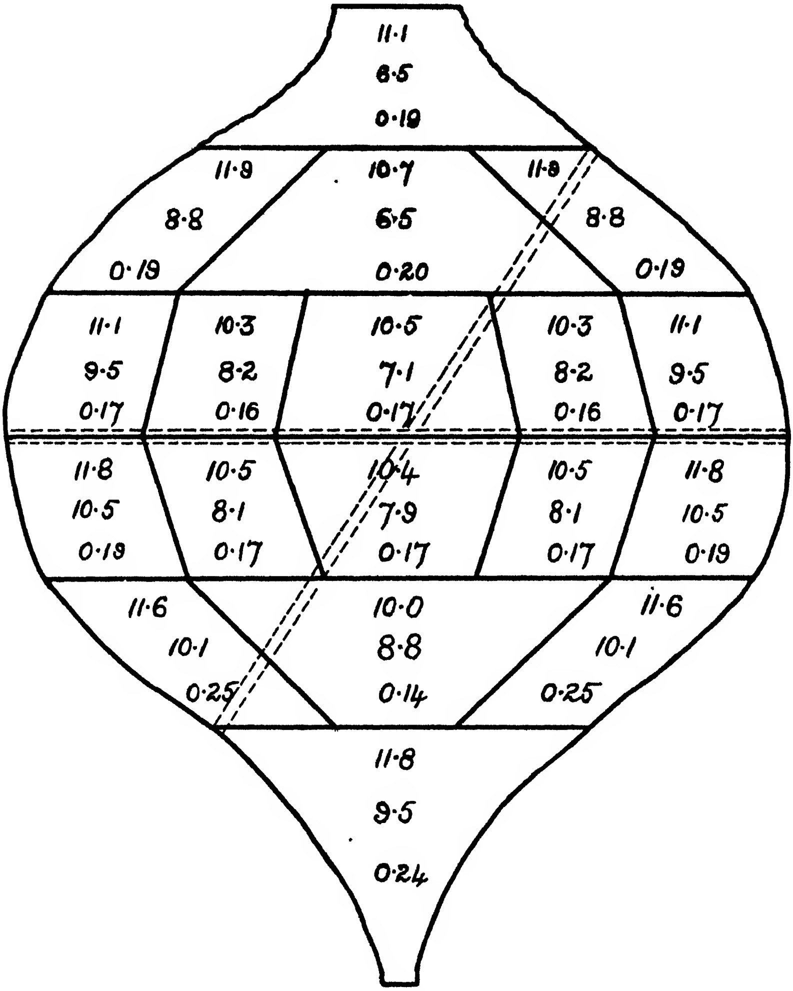

Fig. 1. Yellow-fleshed Globe.

In each "compartment the upper figure gives °/₀ of dry matter, the middle figure °/₀ of sugar, and the lower figure °/₀ of nitrogen.

The coring method of sampling roots may therefore be accepted as reliable, both in our own experience and that of the Continental sugar-beet workers.

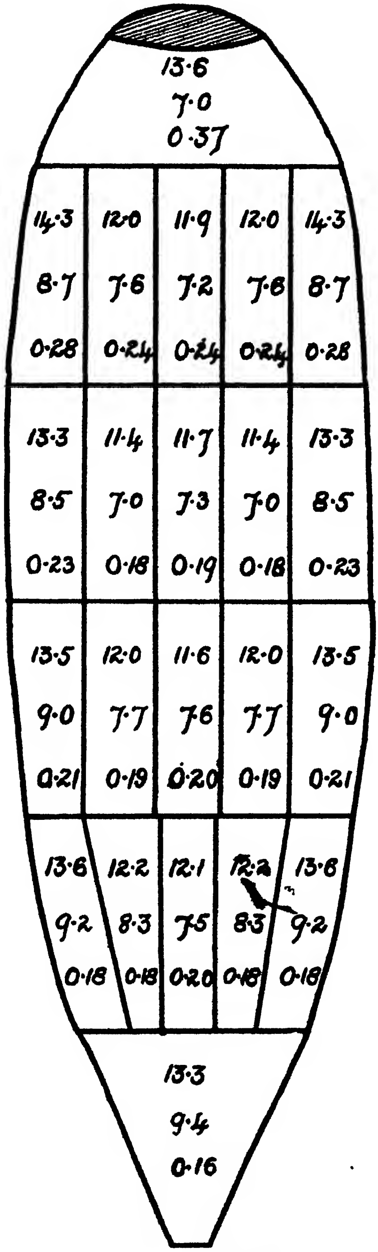

FIG. 2. Long Red.

In each "compartment" the upper figure gives °/$_o$ of dry matter, the middle figure °/$_o$ of sugar, and the lower figure °/$_o$ of nitrogen.

It has already been mentioned that roots are not uniform in composition throughout their substance, and it would therefore appear to be a matter of some importance that the core should be taken in a certain direction. We therefore divided a number of roots into four or five horizontal slices, each of which was further divided into concentric rings. The dry matter, sugar, and nitrogen were then determined in each piece, and the distribution of dry matter and sugar throughout the root was found to be as shown in the figures, pp. 180, 181. Fig. 1 shows the distribution in a Yellow Globe mangel, Fig. 2 in a Long Red. Other experimenters who have used the coring method for sampling roots have taken their cores diagonally through the centre of the root from a point just below the lowest leaf-scar. Examination of Figs. 1 and 2 shows that coring in this manner is liable to two sources of error—firstly, the root changes in composition very rapidly in the region just below the leaf-scars; and secondly, especially in the varieties possessing the long shape, the core is liable to contain much too large a proportion of the poorer quality of material near the centre of the root, and to give therefore low results. To obviate these risks we have taken our cores horizontally through the greatest diameter of the root, the region where variation in composition is least pronounced.

Having settled on the horizontal core for sampling individual roots, it was necessary to determine the number of roots which must be cored in order to obtain a mixed sample representing the composition of the crop. Many of the published analyses of root crops have been made on single roots, but as a rule larger numbers, up to 15 or 20, the numbers taken at Rothamsted, have been wholly or partially sliced or pulped and mixed. Our figures for individual variation were utilised to obtain some definite information on this point.

Table I, opposite, explains itself, and shows that, when using the coring method, samples taken from only 10 roots may give results differing from the mean by nearly ± 1 per cent. Even by sampling 20 roots the error may amount to $\pm 0{\cdot}5$ per cent., but by sampling 50 roots the error is reduced to $\pm 0{\cdot}2$ per cent. or under, and it would appear therefore that at least 50 roots should be cored in order to obtain a really representative sample. Much the same results are obtained by the sector method. All our work has been done on duplicate samples, each taken from 50 roots, and we have found the duplicates to agree quite satisfactorily, the average difference between about 200 duplicate determinations this year being under 0·3 per cent. for dry matter and under 0·2 per cent. for sugar.

TABLE I.

	Sampled by Cores			Sampled by Sectors
	Average of consecutive tens			
Maximum.........	15·40	15·87	15·41	13·40
Minimum........	13·56	14·61	13·60	12·06
Average............	14·70	15·27	14·53	12·76
Error...............	± ·92	± ·63	± ·86	± ·67
	Average of consecutive twenties			
Maximum...... ..	15·15	15·65	14·84	13·24
Minimum	14·32	14·95	13·82	12·30
Average...	14·70	15·27	14·53	12·76
Error...	± ·41	± ·35	± ·51	± ·47
	Average of consecutive fifties			
Maximum.........	14·92	15·38	14·60	12·83
Minimum	14·47	15·21	14·49	12·69
Average......	14·70	15·27	14·53	12·76
Error..	± ·22	± ·08	± ·05	± ·07

The samples of 50 cores from each plot are taken in the field, wrapped in butter-paper, labelled, and sent to the laboratory in tin boxes. They are prepared for analysis the next morning.

ANALYSIS.

Each packet of 50 cores is first cut in halves transversely. One half is at once weighed on a tared shallow aluminium tray, and dried to constant weight at a temperature of 65° C. At this temperature the dry matter practically ceases to lose weight after 48, or at most 72 hours, and no discoloration or charring occurs.

The dried cores, after cooling, are weighed and at once ground in an analytical mill. The powder is further used for determination of nitrogen and other constituents.

The second half of the bundle of cores is reduced to pulp by passing through a small sausage mill. The pulp is placed in a piece of fine linen, and the juice at once squeezed out as completely as possible by hand. When first expressed the juice is light coloured, but frothy and full of air bubbles, and by the time these have risen an oxidase[1] contained in the juice has commenced to form a black precipitate in the upper layers. Specific gravity determination, or measuring, is therefore a matter of some delicacy. We have always taken care to measure the juice for analysis as soon as possible after the froth has subsided.

With these precautions 100 c.c. of juice is measured out, 10 c.c. of basic lead acetate solution added, the mixture shaken and filtered after standing some time. The clear filtrate is polarised at once, and again polarised after inversion by Clerget's method. The percentage of cane sugar is calculated from the change in rotation on inversion, and it is always found that the dextro-rotation of the original juice is rather more than is accounted for by the cane sugar present. The difference corresponds to from 0·1 to 0·5 per cent. of dextrose, an amount which agrees very well with figures given by Miller[2] in his paper on the changes in composition of mangels during storage.

To convert percentage of sugar in the juice into percentage in the root we have adopted the factor 0·93, which was arrived at as follows:

Mean of 90 determinations of specific gravity of juice............ 1·0393
Mean of 12 determinations of percentage of insoluble material
in the root .... 3·04
Percentage of juice therefore = 100 − 3·04 = 96·96.

Factor for converting percentage in juice into percentage in root $= \dfrac{96{\cdot}96}{1{\cdot}0393}$
$= 0{\cdot}93.$

This factor was confirmed by comparing the percentage of sugar in the juice determined as above explained, with the percentage in the root as determined by alcohol extraction.

	I.	II.	III.
Percentage total sugar in juice ...	7·40	6·80	7·10
Percentage total sugar in root by alcohol extraction	6·81	6·25	6·65
Factor	0·92	0·92	0·94

[1] Bertrand, *Ann. Agr.* XXIII. p. 385, 1897.
[2] *R.A.S.E. Journal*, III. XI. p. 57, 1900.

Nitrogen was determined in the finely ground dry matter by Kjeldahl's method, using sulphuric acid containing 5 per cent. of salicylic acid in order to prevent any possible loss of nitrogen due to decomposition of nitrates. Duplicates were found to agree very satisfactorily, the average difference being between 0·02 and 0·03 per cent. Some determinations were made of proteid nitrogen by precipitating the proteids from a suspension of the dry matter in water by means of copper acetate, and determining the nitrogen in the precipitate.

A few fibre estimations were made, using $1\frac{1}{4}$ per cent. sulphuric acid and $1\frac{1}{4}$ per cent. soda, but as the results did not seem to give information of any particular interest, the analyses were discontinued.

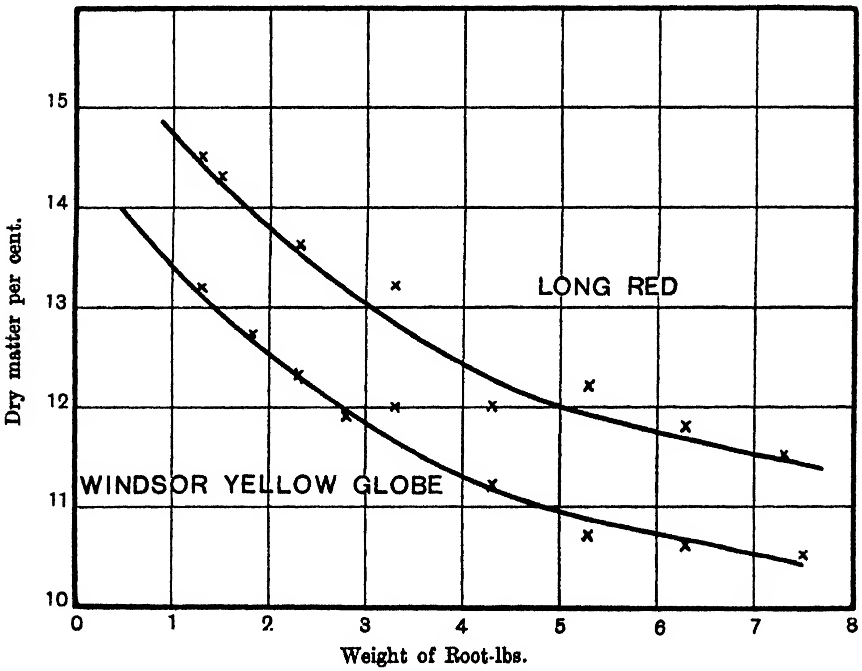

FIG. 3.

VARIATION DUE TO SIZE OF ROOT.

A factor which has to be considered in comparing the results of analyses of different samples of roots is the influence of the size of the root on the percentage of dry matter. It has already been mentioned that several writers and most text-books call attention to this point, and

state that large roots contain more water, and consequently less dry matter than smaller ones.

We have attempted to measure this effect of size by determining the percentage of dry matter in duplicate samples of 50 roots of varying sizes. The results are embodied in Fig. 3, p. 185, and they show that the influence of size is the same in both the varieties which were tried. The following figures give the decrease in dry matter due to each additional lb. in weight of root from 1 to 7.

Weight of root increases		Dry matter decreases by	
From lbs.	To lbs.	White-fleshed globe %	Long red %
1	2	0·9	0·9
2	3	0·7	0·7
3	4	0·5	0·6
4	5	0·4	0·4
5	6	0·25	0·3
6	7	0·2	0·2

It is noticeable that a small change in weight makes a great difference in percentage of dry matter if the roots are small, but when the size of the root attains something like 7 lbs., alteration in weight has a comparatively small effect on the percentage of dry matter. As most of the roots sampled were over 4 lbs. in weight, this factor cannot have caused any very great errors.

Classification of Varieties.

The catalogues of the leading seedsmen of the present day contain an enormous number of named strains of mangels, and in commencing an investigation on the chemical composition of mangels, the question at once arises as to how many of these seedsmen's names represent really distinct types.

The older literature[1] mentions only very few varieties, Long Red, with its sub-strain Hornbeet, so called from its being curved like a cow's horn; Long Yellow; and Red and Yellow Globes; and it was not until the last 20 years or so that the number of varieties has been so greatly multiplied. On comparing the botanical characteristics, and

[1] Wilson, *Our Farm Crops*, Vol. I. p. 407, Edinburgh, 1859; Raynbird, *R.A.S.E. Journal*, I. VIII p. 217, 1847.

the chemical composition, of all the seedsmen's strains we have grown during our three years' work, we find that a large proportion of the strains which have been investigated fall into one or other of the varieties mentioned by the older writers, and one of the first results of our investigations was to show that there are five types of mangels in common cultivation, namely, White-fleshed Yellow Globe, White-fleshed Intermediate, Yellow-fleshed Tankard, Yellow-fleshed Globe, and Long Red, while a number of miscellaneous strains which we have not at present attempted to classify, are occasionally grown.

In the following Table II will be found the yield per acre, the percentages of dry matter, sugar, nitrogen, and fibre, in all the strains we have investigated.

The strains are classified into the above five types, with the exception of the above-mentioned miscellaneous strains which are given separately at the end of the table.

On looking through the analyses of the various strains of the same type grown side by side at the same station it will be seen that they all have the same composition within the limits of error of experiment. Thus in the White-fleshed Globes, the agreement in percentage of dry matter is very close among all the strains which have been grown on the University Farm each year. There were, however, considerable differences between the strains of this variety at Trowse and Saxlingham in 1902. At Saxlingham this was undoubtedly due to the fact that the roots were grown on a somewhat gravelly field which dried out in places where the roots attained only a very small size, with correspondingly high percentages of dry matter (see p. 185). At Trowse the cause of variation is probably different. Webb's New Smithfield, which contained a higher percentage of dry matter than the other strains of the same type, produced a very considerable proportion of roots containing yellow pigment in their flesh. These yellow-fleshed roots were picked out and sampled separately at Field Dalling in 1904, and they were found to contain ·6 per cent. of dry matter and ·4 per cent. of sugar more than the white-fleshed roots among which they were growing.

With regard to the Intermediates, they do not agree among themselves nearly so well as the other types. This point is discussed later.

The Yellow-fleshed Tankards agree among themselves very well, with a few exceptions at the University Farm in 1904, due again to some of the strains producing very small roots. The same remarks apply to Yellow-fleshed Globe and Long Red.

TABLE II.

Name of Variety and Strain	Where grown	Year	Yield per acre. Tons	% Dry Matter	% Sugar	% Nitrogen	% Fibre
White-fleshed Yellow Globe							
Carter's Windsor	University Farm	1902	37·7	11·7	6·9	·175	·71
Sutton's Prize Winner......	,,	,,	37·6	11·5	6·7	—	—
Webb's New Smithfield ...	,,	,,	36·2	11·5	7·2	—	—
Carter's Windsor	Trowse	,,	—	11·1	7·6	·149	·66
Sutton's Prize Winner......	,,	,,	—	10·3	6·2	—	—
Webb's New Smithfield ...	,,	,,	—	12·1	7·7	—	—
Carter's Windsor	Aylsham	,,	—	9·9	6·2	·174	·68
Sutton's Prize Winner......	,,	,,	—	9·7	5·7	—	—
Webb's New Smithfield ...	,,	,,	—	10·5	6·8	—	—
Carter's Windsor	Saxlingham	,,	—	11·5	7·7	·184	·69
Sutton's Prize Winner......	,,	,,	—	13·5	8·2	—	—
Webb's New Smithfield ...	,,	,,	—	12·5	8·1	—	—
Average...............	Four Stations	1902	37·2	11·3	7·1	·161	·69
Carter's Windsor	University Farm	1903	31·5	11·3	6·7	·116	—
,, ...	Trowse	,,	—	9·5	5·5	·162	—
,, ...	Aylsham	,,	—	8·5	4·6	·135	—
,, ...	Saxlingham	,,	—	9·6	4·8	·225	—
,, ...	Ridgmont	,,	—	11·0	6·7	·150	—
Average..............	Five Stations	1903	31·5	10·0	5·7	·158	—
Carter's Windsor	University Farm	1904	20·5	10·5	6·3	·170	—
Sutton's Prize Winner	,,	,,	—	11·1	5·9	—	—
,, Devon	,,	,,	—	11·9	6·6	—	—
,, Yellow	,,	,,	20·4	11·6	6·6	—	—
Daniels' Norwich	,,	,,	—	11·9	7·2	—	—
Cannell's Quantity & Quality	,,	,,	20·7	11·7	6·3	—	—
Carter's Windsor	Trowse	,,	—	11·2	5·7	·222	—
Webb's New Smithfield ..	,,	,,	—	11·1	6·1	—	—
Carter's Windsor	Aylsham	,,	21·7	9·6	5·2	·159	—
Webb's New Smithfield ..	,,	,,	21·8	10·3	6·4	—	—
Carter's Windsor	Ridgmont	,,	—	11·7	6·8	·164	—
,, ...	Field Dalling	,,	—	9·7	5·9	·159	—
Webb's New Smithfield ...	,,	,,	—	10·3	6·5	—	—
Carter's Windsor	Yeldham	,,	—	10·9	6·4	—	—
Sutton's Prize Winner......	,,	,,	—	11·0	6·4	—	—
Carter's Windsor	Hamels Park	,,	—	9·7	5·6	—	—
Average...............	Seven Stations	1904	21·1	10·9	6·2	·175	—
Three Years' Average......	....	....	29·9	10·7	6·3	·165	—
White-fleshed Intermediate							
Sutton's Yellow.........	University Farm	1902	33·5	13·2	8·1	—	—
Webb's Lion	,,	,,	35·7	11·8	6·9	—	—
Average..............	....	1902	34·6	12·5	7·5	—	—
Sutton's Yellow..............	University Farm	1903	28·5	12·7	8·0	·120	—
,, ...	Trowse	,,	—	10·7	6·6	·171	—
,, ...	Aylsham	,,	—	9·5	5·5	·160	—
,, ...	Saxlingham	,,	—	11·7	6·6	·213	—
,, ...	Ridgmont	,,	—	11·8	7·2	·171	—
Average..............	Five Stations	1903	28·5	11·3	6·8	·157	—

TABLE II. (*continued*).

Name of Variety and Strain	Where grown	Year	Yield per acre. Tons	% Dry Matter	% Sugar	% Nitrogen	% Fibre
White-fleshed Intermediate (*continued*)							
Sutton's Yellow..............	University Farm	1904	18·6	12·5	7·7	·167	—
Daniels' Gate Post	,,	,,	—	13·6	8·4	—	—
Sutton's Devon Yellow......	,,	,,	—	11·6	6·6	—	—
Sutton's Yellow..............	Trowse	,,	—	12·8	6·6	·229	—
,, ...	Aylsham	,,	19·6	11·5	6·4	·167	—
,, ...	Ridgmont	,,	—	11·9	6·5	·169	—
,, ...	Field Dalling	,,	—	10·7	6·5	·161	—
Average....	Five Stations	1904	19·1	12·1	7·0	·179	—
Three Years' Average......	....	....	27·4	12·0	7·1	·168	—
Yellow-fleshed Tankard							
Sutton's Golden	University Farm	1902	32·0	14·3	8·8	·162	·72
Webb's Yellow-fleshed	,,	,,	31·8	13·7	8·6	—	—
Sutton's Golden	Trowse	,,	—	13·6	8·7	·185	·77
,, ...	Aylsham	,,	—	12·5	8·4	·190	·81
,, ...	Saxlingham	,,	—	14·1	9·5	·240	·74
Average.....	Four Stations	1902	31·9	13·6	8·8	·194	·76
Sutton's Golden	University Farm	1903	25·8	12·9	8·2	·118	—
Webb's Yellow-fleshed......	,,	,,	—	13·3	8·8	—	—
Sutton's Golden	Trowse	,,	—	12·3	7·6	·179	—
Webb's Yellow-fleshed	,,	,,	—	12·9	7·9	—	—
Sutton's Golden	Aylsham	,,	—	9·6	5·7	·161	—
Webb's Yellow-fleshed	,,	,,	—	10·5	6·1	—	—
Sutton's Golden	Saxlingham	,,	—	12·7	7·2	·247	—
Webb's Yellow-fleshed	,,	,,	—	13·3	7·6	—	—
Sutton's Golden	Ridgmont	,,	—	12·4	7·7	·126	—
Webb's Yellow-fleshed ...	,,	,,	—	12·4	7·9	—	—
Average...	Five Stations	1903	25·8	12·2	7·5	·168	—
Sutton's Golden	University Farm	1904	18·3	13·4	8·3	·201	—
Cannell's Golden	,,	,,	12·0	14·2	8·2	—	—
King's Golden	,,	,,	—	15·5	9·1	—	—
Sutton's Golden.............	Trowse	,,	—	13·1	7·0	·235	—
,, ...	Aylsham	,,	18·3	12·5	7·1	·184	—
,, ...	Ridgmont	,,	—	13·5	7·9	·181	—
,, ...	Field Dalling	,,	—	12·0	7·0	·185	—
Average.............	Five Stations	1904	16·2	13·4	7·8	·197	—
Three Years' Average......	....	....	24·6	13·1	8·0	·186	—
Yellow-fleshed Globe							
Sutton's Golden	University Farm	1902	31·1	14·6	9·6	·191	·76
Webb's Golden King	,,	,,	30·3	15·2	9·7	—	—
Carter's Goldfinder	,,	,,	32·0	14·9	9·1	—	—
Sutton's Golden	Trowse	,,	—	15·0	9·6	·216	·88
,, ...	Aylsham	,,	—	13·0	8·5	·207	·81
,, ...	Saxlingham	,,	—	14·2	8·7	·152	·78
Average.............	Four Stations	1902	31·2	14·4	9·2	·192	·81

TABLE II. (*continued*).

Name of Variety and Strain	Where grown	Year	Yield per acre. Tons	% Dry Matter	% Sugar	% Nitrogen	% Fibre
Yellow-fleshed Globe (*cont.*)							
Sutton's Golden	University Farm	1903	25·5	13·4	8·7	·137	—
Webb's Golden King.........	,,	,,	27·5	14·4	9·4	—	—
Carter's Goldfinder	,,	,,	—	12·9	8·5	—	—
Sutton's Golden	Trowse	,,	—	12·1	7·3	·194	—
Webb's Golden King..... ...	,,	,,	—	12·0	6·9	—	—
Carter's Goldfinder	,,	,,	—	12·1	7·2	—	—
Sutton's Golden	Aylsham	,,	—	11·0	6·9	·167	—
Webb's Golden King	,,	,,	—	10·6	6·3	—	—
Carter's Goldfinder	,,	,,	—	9·9	5·4	—	—
Sutton's Golden	Saxlingham	,,	—	12·9	7·5	·225	—
Webb's Golden King	,,	,,	—	12·4	6·8	—	—
Carter's Goldfinder	,,	,,	—	12·7	7·2	—	—
Sutton's Golden	Ridgmont	,,	—	12·9	8·1	·150	—
Webb's Golden King	,,	,,	—	13·0	8·0	—	—
Carter's Goldfinder	,,	,,	—	12·1	7·5	—	—
Average..............	Five Stations	1903	26·5	12·3	7·3	·175	—
Sutton's Golden	University Farm	1904	16·7	13·9	8·2	·227	—
Webb's Golden King	,,	,,	19·7	14·6	8·8	—	—
King's Golden	,,	,,	—	14·1	8·3	—	—
,, Orange	,,	,,	18·3	14·0	8·3	—	—
Cannell's New Century ...	,,	,,	16·3	14·7	8·8	—	—
Daniels' Coronation	,,	,,	15·5	14·6	9·1	—	—
Sutton's Golden	Trowse	,,	—	13·7	7·9	·251	—
,, ...	Aylsham	,,	17·4	12·2	7·3	·182	—
,, ...	Ridgmont	,,	—	13·2	8·3	·177	—
,, ...	Field Dalling	,,	—	11·9	7·5	·186	—
,, ...	Hamels Park	,,	—	11·8	7·4	—	
Webb's Golden King	Yeldham	,,	—	14·8	9·1	—	—
Average..............	Seven Stations	1904	17·3	13·6	8·2	·205	
Three Years' Average......	....	....	25·0	13·4	8·2	·191	–
Long Red							
Sutton's Mammoth	University Farm	1902	33·2	14·7	8·7	·154	·81
Carter's Mammoth	,,	,,	31·0	15·1	8·9	—	—
Sutton's Mammoth	Trowse	,,	—	13·6	8·4	·149	·77
,, ...	Aylsham	,,	—	11·9	7·6	·170	·82
,, ...	Saxlingham	,,	—	14·1	9·4	·152	·84
Average..............	Four Stations	1902	32·1	13·9	8·6	·156	·81
Sutton's Mammoth	University Farm	1903	34·7	13·5	8·5	·110	—
,, ...	Trowse	,,	—	12·4	7·4	·216	—
,, ...	Aylsham	,,	—	11·5	6·4	·127	—
,, ...	Saxlingham	,,	—	12·4	7·0	·182	—
,, ...	Ridgmont	,,	—	12·3	7·8	·084	—
Average..............	Five Stations	1903	34·7	12·4	7·4	·144	—
Sutton's Mammoth	University Farm	1904	20·7	13·2	7·8	·173	—
,, Elvetham	,,	,,	—	15·5	9·5	—	—
Sutton's Mammoth	Trowse	,,	—	13·1	7·2	·214	—
,, ...	Aylsham	,,	25·4	11·2	6·4	·164	—
,, ...	Ridgmont	,,	—	13·3	7·8	·156	—
,, ...	Field Dalling	,,	—	12·1	7·3	·143	—
,, ...	Hamels Park	,,	—	11·1	6·8	—	—
,, ...	Yeldham	,,	—	14·0	8·6	—	—
Average..............	Seven Stations	1904	23·0	12·9	7·7	·170	—
Three Years' Average......	....	....	29·9	13·1	7·9	·157	—

TABLE II. (*continued*).

Name of Variety and Strain	Where grown	Year	Yield per acre. Tons	% Dry Matter	% Sugar	% Nitrogen	% Fibre
MISCELLANEOUS:							
Long Yellow							
Sutton's	University Farm	1903	27·5	14·5	9·3	—	—
,,	Trowse	,,	—	12·4	7·4	—	—
,,	Aylsham	,,	—	11·4	6·5	—	—
,,	Saxlingham	,,	—	12·8	7·5	—	—
,,	Ridgmont	,,	—	13·6	8·6	—	—
Average	Five Stations	1903	27·5	13·0	7·9	—	—
Sutton's	University Farm	1904	13·1	14·7	8·8	—	—
Carter's	,,	,,	14·6	14·3	8·5	—	—
Average		1904	13·8	14·5	8·6	—	—
Crimson Tankard							
Sutton's	University Farm	1902	30·7	13·5	8·4	—	—
,,	,,	1903	—	13·4	8·0	—	—
,,	,,	1904	13·3	12·9	7·5	—	—
,,	Yeldham	,,	—	13·6	8·0	—	—
Average				13·3	8·0	—	—
Carter's **1901**	University Farm	1902	31·0	14·9	8·7	—	—
,,	Trowse	,,	—	14·7	9·2	—	—
,,	Aylsham	,,	—	12·8	8·0	—	—
,,	Saxlingham	,,	—	14·0	9·0	—	—
,,	University Farm	1903	—	12·8	7·8	—	—
Carter's **Red Globe**	University Farm	1904	—	16·7	10·3	—	—
,, **Red Emperor**	,,	,,	14·9	14·8	9·2	—	—
,, **Golden Intermediate**	,,	,,	12·1	12·7	7·1	—	—
Cannell's **Red Intermediate**	,,	,,	18·0	15·3	9·3	—	—
Webb's **Champion**	University Farm	1902	32·1	14·2	8·8	—	—
Daniel's **Berkshire**	,,	1904	—	13·4	8·4	—	—
,, **Somerset**	,,	,,	—	13·3	7·9	—	—
Sugar Mangel							
Carter's	University Farm	1902	27·9	16·0	10·9	—	—
,,	Trowse	,,	—	15·7	9·9	—	—
,,	Aylsham	,,	—	14·7	9·4	—	—
,,	Saxlingham	,,	—	15·8	11·0	—	—
Average	Four Stations	1902	27·9	15·6	10·3	—	—
Carter's	University Farm	1903	—	13·0	7·6	—	—
Sutton's	,,	,,	—	13·0	7·6	—	—
Average		1903	—	13·0	7·6	—	—
Carter's	University Farm	1904	13·5	15·4	9·2	—	—
Sutton's	,,	,,	18·3	15·3	9·2	—	—
Average		1904	15·9	15·4	9·2	—	—
Three Years' Average				14·7	9·0	—	—

Among the Yellow-fleshed Globes, Goldfinder and Golden King have generally given low results for dry matter and sugar. These two strains, like New Smithfield, do not come quite true, but produce a certain number of white-fleshed roots. These white-fleshed roots were picked out and sampled separately at the University Farm in 1904, and were found on analysis to contain 1·7 per cent. dry matter and ·7 per cent. sugar less than the yellow-fleshed roots of the same strain from the same plot.

The presence of a variable proportion of such white-fleshed roots in the plots of these strains may well account for their variability in composition.

We now proceed to give the characteristics of each of the five chief types in the light of the information contained in the above table.

White-fleshed Globe.

Characters. Root globe-shaped, with white flesh, skin yellow below ground, shading through white to green above. Leaves small, erect, and very bright green, with petioles which are usually greenish-white, but often turn yellowish as the season advances. Nearly every seedsman has several strains of this variety, which differ chiefly in purity, presumably because some of them have been more carefully selected than others.

All the strains are extremely vigorous and grow large crops of very uniformly shaped roots, but the percentages of dry matter, sugar, and nitrogen are low compared with other varieties.

White-fleshed Intermediate.

Characters. These are, on the whole, very similar to the characters of the White-fleshed Globe, with the following exceptions: The root is more elongated along its vertical axis than in the globe; the skin of the root and of the petioles is often more deeply pigmented; and the variety is not so vigorous, and grows usually rather smaller crops of less uniform shape, but containing higher percentages of dry matter, sugar, and nitrogen.

The various seedsmen's strains do not resemble each other nearly so closely as do the strains of White-fleshed Globe, nor does each strain come so true from seed.

These facts, and the absence of references to Intermediate in the older literature, suggest that it is probably a new variety which has not yet been selected for a long-enough period to secure uniformity.

Yellow-fleshed Tankard.

Characters. Root usually tankard shaped, but most strains produce

some globe-shaped roots; flesh yellow; skin shading from crimson at the base, through orange, to brownish near the crown; leaves larger than in White-fleshed Globe; petioles usually orange. There is a large number of strains of this type, which closely resemble each other. They do not crop nearly so well as the White-fleshed Globe, but contain considerably more dry matter, sugar, and nitrogen.

Yellow-fleshed Globe.

Characters on the whole very similar to the Tankards, the only difference being that the majority of the roots of this variety are globular in shape. There is a very large number of strains, which differ considerably in external characters, notably in the colour of the skin of the root and of the petioles. Those strains which have a less decided orange colour in skin and petioles do not always come true from seed, but produce a considerable proportion of white-fleshed roots (see p. 192). The cropping power and the chemical composition are on the average almost exactly the same as in Yellow-fleshed Tankard.

Long Red.

Characters. Root long and narrow; flesh pink; skin crimson or magenta, shading to brown near the crown; leaves dark green and erect. There are very few strains of this type, and all are extremely uniform. The pigment which they contain seems to be quite distinct from that of the yellow-fleshed varieties. We have noticed that it is completely precipitated when the juice is clarified with basic lead acetate in preparing for sugar estimation, whilst the yellow pigment is not. The Long Red grows very large crops on soils which suit it. On the average of our three years' trials its cropping power is just equal to that of Yellow-fleshed Globe, and it contains much more dry matter and sugar, but less nitrogen.

MISCELLANEOUS VARIETIES.

In the course of our work we have come across a number of mangels which cannot be included in either of the five types described above, and which we have not attempted to classify, either because they are not sufficiently widely grown to make it worth while, or because they are not fixed types, or because we have not as yet accumulated sufficient information about them. We therefore give our results with them as far as they go at present.

Long Yellow.

This mangel resembles Long Red in all characters except that it is coloured yellow instead of red. It appears to be quite a distinct and constant variety, but, so far as we know, is not widely grown.

It has not cropped quite so well in our trials as Long Red, but gives on the average about the same percentages of dry matter and sugar.

Crimson Tankard.

This too appears to be quite a distinct and constant variety, similar in every way except colour to the Yellow-fleshed Tankards.

Carter's 1901.

Characters. Practically those of Yellow-fleshed Globe.

This is quite an interesting strain, lately put on the market by Messrs James Carter & Co., who state that it has been produced by selecting roots of superior chemical composition for seed-mothers. The actual method of selecting is not stated, but the mother-roots were apparently picked out for high specific gravity of their juice, which we show (pp. 206 and 210) to be by no means a reliable criterion of high content of dry matter or sugar. That the method of selection was not successful in making improvement is shown by the following figures, which give the percentages of dry matter and sugar in Carter's "1901," and in the Yellow-fleshed Globes grown side by side with it at four stations in 1902.

	Average of 4 Stations	
	Dry matter %	Sugar %
Carter's 1901	14·1	8·7
Other yellow-fleshed Globes ...	14·4	9·2

Carter's Red Globe, Red Emperor, and **Golden Intermediate,** and **Cannell's Red Intermediate,** are new mangels which we have only grown once, and about which we have not at present sufficient information.

Webb's Champion, Daniel's Berkshire and **Somerset,** are more like White-fleshed Globe than anything else, but in our trials they have not come true. A very considerable proportion of the roots they produce are more or less yellow in the flesh, and contain rather higher percentages of dry matter and sugar than the typical strains of White-fleshed Globe.

Sugar Mangel.

Some years ago several Continental seedsmen produced sugar mangels by crossing sugar beet with different varieties of mangels, and English seedsmen have lately been following their example.

We have tried two strains, which are distinct in appearance, but very similar in composition. In 1902 Carter's Sugar Mangel gave very high percentages of dry matter and sugar at each of our four stations, but had a somewhat awkward shape and habit of growth, burying itself deeply in the ground, and at the same time it did not come true. From every plot of it we picked out roots which were deep pink, almost like a Long Red mangel, others which were pure white like a sugar beet, and others which were intermediate in colour. A very large proportion of the plants also ran to seed the first year. These defects have been less in evidence in 1903 and 1904.

SUMMARY OF CLASSIFICATION.

In the following table are collected the three years' averages at all stations of all the strains of the five chief types which have been grown:

Name of Type	Yield per acre. Tons	Dry matter %	Sugar %	Nitrogen %
White-fleshed Globe	29·9	10·7	6·3	0·165
White-fleshed Intermediate ...	27·4	12·0	7·1	0·168
Yellow-fleshed Tankard.........	24·6	13·1	8·0	0·186
Yellow-fleshed Globe	25·0	13·4	8·2	0·191
Long Red	29·9	13·1	7·9	0·157

These figures summarise the remarks already made about the chemical composition of each type. From them can be calculated the yield of actual dry food per acre produced on the average by each variety. This is done below:

Name of type	Dry matter per acre. Tons	Sugar per acre. Tons	Nitrogen per acre. lbs.
White-fleshed Globe	3·20	1·88	111
White-fleshed Intermediate ...	3·29	1·94	103
Yellow-fleshed Tankard.........	3·22	1·96	102
Yellow-fleshed Globe	3·35	2·05	107
Long Red	3·92	2·36	105

Inspection of the figures in the above table shows extraordinary similarity in yield of dry matter, sugar, and nitrogen per acre in all the types except Long Red, which stands out by itself as producing rather more than half a ton per acre of dry matter in excess of any of the other types. In the other four types cropping power and percentage of dry matter appear to be practically inversely proportional, but Long Red crops as heavily as White-fleshed Globe, and contains as much dry matter per cent. as Yellow-fleshed Globe and Tankard. Consequently it is the type which produces most dry food per acre.

Another point of interest in comparing the different types is the relative composition of their dry matter. Figures dealing with this subject are given below:

Name of Type	Composition of dry matter	
	Sugar %	Nitrogen %
White-fleshed Globe	59	1·52
White-fleshed Intermediate .	59	1·46
Yellow-fleshed Tankard...... ..	61	1·45
Yellow-fleshed Globe	61	1·45
Long Red	60	1·23

There is evidently very little variation as regards the average percentage of sugar in the dry matter of the different varieties, the white-fleshed varieties produce on the average a slightly less sugary, and rather more nitrogenous, dry matter than the yellow or red-fleshed kinds. Long Red contains exactly the average proportion of sugar, but is very distinctly less nitrogenous.

Feeding experiments are in progress at the present time with the object of testing the practical feeding value, if any, of these differences in composition of dry matter.

During the last few years several investigations on mangels have been published, both in England and on the Continent, which may in some respects be compared with our own work. In order to make the figures as comparable as possible, we have recalculated them all to a uniform basis by taking the average yield and composition of the White-fleshed Globes in each case as 100.

We are thus able to compare our results with those obtained by Druce at Holmes Chapel in Cheshire[1], by Foulkes at Harper-Adams

[1] *Report of Holmes Chapel Agric. and Hortic. School, Cheshire, C. C.* 1900.

College in Shropshire[1], by Paturel in Finisterre[2], and by Wohltmann at Poppelsdorf in Germany[3].

The comparative figures are given in the annexed table:

Name of Type	Relative Cropping Power, White-fleshed Globe = 100									
	Cambridge University				Holmes Chapel	Harper Adams		Finisterre	Poppelsdorf	
	1902	1903	1904	Av.	1900	1903	1904	1897	1904	Av.
White-fleshed Globe	100	100	100	100	100	100	100	100	100	100
White-fleshed Intermediate	93	91	90	91	89	73	91	90	102	89
Yellow fleshed Tankard	86	82	77	81	77	73	79	71	81	76
Yellow-fleshed Globe	84	84	82	83	75	63	82	70	—	72
Long Red	86	110	108	101	88	—	94	100	—	93
	Relative Richness in Dry Matter, White-Fleshed Globe = 100									
				Av.						Av.
White fleshed Globe	100	100	100	100	100	100	100	100	100	100
White fleshed Intermediate	110	113	111	112	108	100	93	108	114	105
Yellow-fleshed Tankard	120	122	123	122	122	128	120	155	136	132
Yellow-fleshed Globe	127	123	125	125	129	121	112	143	—	126
Long Red	123	124	119	122	109	—	103	120	—	111

Our figures for both cropping power and relative richness in dry matter are very fairly uniform from year to year, and the average, representing as it does the results of three years at a number of stations, is probably quite reliable as showing the relative merits of the five varieties. It will be noticed that the average of the results of the other four workers quoted agrees fairly well with our own average. There are, however, discrepancies in the results of individual workers, for instance, the low figure for dry matter in Intermediate at Harper-

[1] *Reports of Harper-Adams Agric. Coll.* 1903–4.
[2] *Ann. Agron.* xxiv. p. 97, 1898.
[3] *Illust. Land. Zeit.* xxiv. Dec. 1904.

Adams College in 1904, and the high figure for dry matter obtained by Paturel and Wohltmann for Tankard and Yellow-fleshed Globe.

These discrepancies are probably due to errors in sampling: thus at Holmes Chapel the number of roots taken for sampling was only 12, Paturel took only four roots, Wohltmann averaged the analyses of only three roots for dry matter and nine for sugar. We have no information as to the number of roots sampled at the Harper-Adams College.

SEASONAL VARIATION.

It has already been mentioned that the figures for the Rothamsted mangel plots vary very greatly from year to year.

The extent of the variation is very large, from 8·82 per cent. dry matter on the dung, superphosphate, and nitrate plot in 1895 to 15·39 per cent. on the same plot in 1887. It is noteworthy that the crop also differed widely in these two years. In 1887 it amounted on the plot in question to not more than 3·1 tons per acre, while in 1895 the crop on the same plot was 20·35 tons.

On plotting the percentage of dry matter and the crop per acre side by side it is seen that very frequently a large crop means a low percentage of dry matter, and *vice versâ*, but not always, as for instance in 1899, when the crop was only 12 tons per acre, and the dry matter only 9·49 per cent., and again in 1889, when both crop and dry matter were high, 33·95 tons per acre and 12·93 per cent. It appears therefore that, while the conditions of season which tend to produce large crops generally also produce crops containing low percentages of dry matter, yet conditions may occasionally arise which produce large crops with high percentages of dry matter, and small crops with low percentages.

The year 1895, when the percentage of dry matter was lowest, was characterised by a wet, cold, sunless summer, while in 1887, when the dry matter was highest, the summer was extremely hot, and rainless for long periods.

Broadly speaking, a wet summer is likely to produce roots of low dry matter, a dry one roots with much dry matter.

Our figures for the three seasons 1902, 1903, and 1904 agree quite well with this supposition. The figures for crop per acre, dry matter, percentage of sugar and nitrogen in the dry matter, and rainfall during the summer months for the three years in question are given below.

CROP, COMPOSITION, AND RAINFALL.

Average of all plots at all stations.

Year	Crop per acre. Tons	Dry Matter %	Percentage in Dry Matter		Rainfall, May to September	Rainfall, May and June	Rainfall, July, August and September
			Sugar	Nitrogen.			
1902	33·7	13·1	64	1·34	10·75	6·31	4·44
1903	29·4	11·6	60	1·38	16·38	6·62	9·76
1904	19·3	12·6	58	1·53	8·08	2·33	5·75

1902. The spring of this year was showery, and the early summer rainfall was sufficient in quantity and regularly distributed, so that a good plant was obtained on all the plots, and an excellent early growth was made. August again was showery, and the good growth was continued, which ensured a good crop. September was dry and sunny and very favourable for ripening, which accounts for the high percentage of dry matter containing much sugar and little nitrogen.

1903 was also a favourable year for obtaining a plant, but the summer was wet and sunless, and growth was therefore slow. The autumn was also wet and cold, and consequently bad for ripening. The absence of sun caused the roots to remain small, and give therefore a low yield per acre, and the wet, cold autumn preventing ripening, gave low dry matter containing less sugar and rather more nitrogen than the 1902 crop.

1904 was characterised by deficient rainfall in the early summer, which made many blanks in the plant and checked the early growth. Favourable weather was experienced in August and September, and growth continued so late that ripening was imperfect. The early check prevented all chance of a good crop, and the late ripening caused the roots to be low in dry matter and sugar and high in nitrogen.

Summarising the results of the three years, the crop seems to depend on suitable rainfall in the early summer and again in early autumn, and warmth and sun are also required; high dry matter and sugar and low nitrogen are produced by warm, sunny, dry weather for the ripening of the roots in September.

MANURIAL VARIATION.

It is generally taken for granted that the manuring of mangels causes a great variation in composition, and that this is so under certain circumstances is shown by examination of the following figures extracted from Rothamsted *Memoranda,* 1901, and from information given by Mr A. D. Hall.

Manuring per acre	Yield per acre. Tons*	Dry Matter† %	Weight of root. lbs†.	Total Sugar in Dry Matter† %
Farmyard Manure, 14 tons per acre	17·4	13·4	2·44	67
Farmyard Manure + 3 cwt. Super. + 4½ cwt. Sulphate of Potash + 5 cwt. Nitrate of Soda	25·2	11·6	3·95	59
3½ cwt. Super. + 5 cwt. Nitrate of Soda	15·4	11·9	2·47	63
3½ cwt. Super. + 4½ cwt. Sulphate of Potash .	4·5	14·9	·74	67
3½ cwt. Super. + 4½ cwt. Sulphate of Potash + 5 cwt. Nitrate of Soda	15·4	11·8	3·16	67

* Average, 1876–1900. † Average, 1900 and 1902.

Certain points stand out clearly; for instance, mineral manures alone have made very little increase in the crop, and correspondingly little decrease in the percentage of dry matter. Nitrogenous manures have when used with minerals made great increases in the crop and great decreases in the percentage of dry matter. Farmyard manure has acted as a nitrogenous manure, and has both increased the crop and decreased the dry matter.

It appears therefore that any manuring which increases the crop tends to decrease the percentage of dry matter, and, as the figures show, the percentage of sugar in the dry matter.

It is noteworthy that as the size of root has increased under manuring, the percentage of dry matter has decreased. The extreme variation in weight of root, 3·2 lbs., corresponds according to the diagram (p. 185) to a variation in content of dry matter of 2½ per cent. The figures in the above table show a variation of 3·3 per cent. in content of dry matter, which is considerably greater than would be caused by variation in size. It would appear therefore that manures affect the composition in some way other than by merely altering the size of root, and this is indicated also by comparison of plots getting farmyard manure alone and superphosphate and nitrate alone, the former producing roots with higher percentage of dry matter though of the same

size. Probably this outside influence is the imperfect ripening resulting from the excessive dressing—5 cwt.—of nitrate of soda

From the above paragraph it is evident that manurial treatment may, under the exceptional conditions of the Rothamsted plots, become a very important factor in the composition of the mangel crop.

These conditions, continuous growth of mangels on the same plot year after year with the same manure, do not, however, occur in ordinary practice, and it remains to be seen how far manuring influences the composition of mangels grown in the course of ordinary farming.

We carried out trials on this point in 1903 at the University Farm, and a more complete trial at four stations in 1904.

The figures are given below:

UNIVERSITY FARM, 1903.

Manuring per acre	Dry Matter %	Sugar %	Nitrogen %
Farmyard Manure, 10 tons	13·8	8·8	0·128
Farmyard Manure + 40 lbs. N. + 25 lbs. P_2O_5 + 25 lbs. K_2O .	12·9	8 2	0·130
Farmyard Manure + 40 lbs. N. + 100 lbs. P_2O_5 + 80 lbs. K_2O	13·0	8·3	0·131
40 lbs. N. + 100 lbs. P_2O_5 + 80 lbs. K_2O	13·3	8 5	0·136

The 1903 results bring out several points—the variation with different manuring in the ordinary course of farming is quite small compared with that found at Rothamsted, but in the same direction. Thus the addition of artificials to farmyard manure decreased the percentage of dry matter and sugar; and the excessive amount of nitrogen used with the farmyard manure, without enough phosphate and potash to balance it, gave the lowest percentage of dry matter, no doubt again on account of delayed ripening.

The 1904 results Table III at five stations are very satisfactory. The effects of the manures, both on yield per acre and on composition, are very concordant at the different stations, and the average results show that every manuring has given more or less increase in crop and more or less decrease in dry matter and sugar Farmyard manure especially has been active in decreasing the percentage of dry matter and of sugar, and the dry matter of the roots grown on the farmyard manure plots contains a lower percentage of sugar than that of the artificially manured plots.

TABLE III. Crop Results and Analyses, 1904.

Manuring per acre	University Farm			Warham Norfolk		Hethersett Norfolk		Lydgate Suffolk			Eldo House Suffolk			Average				
	Yield per acre. Tons	Dry Matter %	Sugar %	Dry Matter %	Sugar %	Dry Matter %	Sugar %	Yield per acre. Tons	Dry Matter %	Sugar %	Yield per acre. Tons	Dry Matter %	Sugar %	Yield per acre. Tons	Dry Matter %	Sugar %	Sugar in Dry Matter %	Weight of Root in lbs. at all Stations
Unmanured	14·5	13·5	7·7	12·3	7·1	14·1	9·0	4·8	15·5	8·7	12·8	16·8	11·0	10·7	14·4	8·7	60	2·2
40 lbs. N. 80 lbs. P_2O_5 80 lbs. K_2O	23·0	12·1	7·3	11·6	6·5	13·3	7·9	9·6	15·0	8 9	15·7	16·5	10·9	16·1	13·6	8·3	61	3·0
40 lbs. N. 80 lbs. P_2O_5	19·5	12·5	7·5	11·8	6·6	13·4	7·6	8·2	15·8	8·2	14·0	17·1	11·0	13·9	14·1	8·2	58	2·9
40 lbs. N. 80 lbs. K_2O	21·3	12·2	7·1	12·0	7·1	12·9	7·5	5·9	15·6	9·1	15·1	16·8	10·8	14·1	13·9	8·3	60	2·9
80 lbs. P_2O_5 80 lbs. K_2O	20·5	13·2	8·0	12·4	6·9	13·3	8·1	8·6	14·6	8·6	13·2	17·2	11·2	14·1	14·1	8·6	61	2·8
Farmyard Manure, 12 tons	22·5	10·7	6·2	10·7	5·8	11·1	6·0	8·3	14·1	7·9	13·9	16·4	10·5	14·1	12·6	7·3	58	3·1
Farmyard Manure +40 lbs. N. 80 lbs. P_2O_5 80 lbs. K_2O	28·9	10·7	6·2	10·6	6·0	10·2	5·1	9·8	13·8	7·8	17·9	15·5	9·9	18·9	12·2	7·0	57	3·0

The weight of the roots on the different plots was very fairly uniform, and the difference in size was not nearly enough to account for the difference in composition.

The greatest variation is quite small compared with the Rothamsted figures, but with farmyard manure and artificials the decrease in the percentage of dry matter is still quite considerable. In spite of this decrease the farmyard manure increased the crop so much that it produced more dry matter per acre. Thus:

	Tons.
Dry matter per acre grown with mixed artificials	2·2
" " " " " + farmyard manure	2·3

Variation with Soil.

During the three years over which our work has already extended we have grown mangels at seven stations, and every year certain stations have produced roots which have been consistently high or low in content of dry matter, sugar, or nitrogen, as can be seen from the following table.

Station	1902 Average of			1903 Average of			1904 Average of			Average of 3 years		
	8 varieties		4 vars.	9 varieties		5 vars.	5 varieties					
	Dry Matter %	Sugar %	Nitrogen %	Dry Matter %	Sugar %	Nitrogen %	Dry Matter %	Sugar %	Nitrogen %	Dry Matter %	Sugar %	Nitrogen %
University Farm	13·6	8·4	·171	13·2	8·4	·120	12·7	7·2	·187	13·2	8·0	·159
Trowse	13·3	8·4	·175	11·8	7·1	·184	12·8	6·9	·230	12·6	7·5	·196
Aylsham	11·9	7·6	·184	10·3	5·9	·150	11·4	6·5	·171	11·2	6·7	·168
Saxlingham	13·6	8·9	·173	12·3	6·9	·213	—	—	—	—	—	—
Ridgmont..	—	—	—	12·4	7·7	·117	12·7	7·4	·169	—	—	—
Field Dalling ...	—	—	—	—	—	—	11·3	6·8	·167	—	—	—

As regards dry matter, examination of the table shows that the University Farm has consistently produced roots of high quality, while Aylsham has just as consistently produced roots of low quality, and Trowse has, except in 1904, been intermediate. The extreme variation between the stations has been from 1·5 to 3 per cent., and the question at once arises, is this variation correlated with varying size of root?

Unfortunately the roots were not weighed in 1902 and 1903, but in 1904 we took the precaution to weigh the 100 roots which were cored for each pair of samples, and for this year therefore we can compare the average size of root at each station with the percentage of dry matter, as is done in the following table:

WEIGHT OF ROOT AND DRY MATTER, 1904.

	Trowse	University Farm	Aylsham	Field Dalling
Weight of Root—lbs.	3·4	3·6	5·2	5·7
Dry Matter %...... .	12·8	12·7	11·4	11·3

It is evident at once that as the average weight of root increases the percentage of dry matter decreases, and, taking the extremes, an increase of 2·3 lbs. in average weight of root corresponds with a decrease of 1·5 per cent. of dry matter. Referring to the curves connecting weight of root and dry matter on page 185, it will be seen that an increase in weight of root from 3·4 lbs. to 5·7 lbs. corresponds to a decrease in dry matter of 1·1 per cent.

The 1904 figures therefore appear to indicate that the variation in percentage of dry matter from one farm to another is largely to be explained by varying size of root. It must be remembered that these figures refer to one year only, and we do not therefore feel justified in stating that varying size of root explains everything in this connexion, especially as the figures show that the dry matter at the different stations has a varying composition, as is shown below.

Station	Percentage in Dry Matter	
	Sugar	Nitrogen
University Farm.........	62	1·24
Trowse	59	1·62
Aylsham	59	1·54
Saxlingham	60	1·61
Ridgmont..	61	1·16

Thus the dry matter of the roots grown at the University Farm and at Ridgmont is characterised by a high percentage of sugar and a low

percentage of nitrogen, while Trowse, Aylsham, and Saxlingham produced roots whose dry matter was, on the contrary, rich in nitrogen and relatively poor in sugar.

We are extending this branch of our investigation to other types of soil, and hope this year to grow mangels on peats and on clay soils. In the meantime it may be of interest to record the following partial analyses of the soils on which we have already worked.

Station	Percentage in Air-dried Soil			
	Water	Organic Matter	Particles over ·2 mm.	Particles ·2—·04 mm.
University Farm.........	2·80	5·4	39·1	15·1
Saxlingham	0·70	3·7	51·1	31·6
Field Dalling	0·69	8·3	49·1	16·7
Ridgmont..............	6·90	6·4	36·5	8·3
Trowse	0·86	3·8	58·0	20·8
Aylsham	0·85	3·9	33·3	35·4

Individual Variation.

In discussing the question of sampling we have already had occasion to mention the occurrence of very considerable variation in the chemical composition of individual roots of the same strain, even when grown side by side in the same field.

Thus in 1902 we found in 200 individual roots of Sutton's Golden Globe four roots containing less than 11 per cent. of dry matter and four roots containing over 18 per cent. Similar results were also obtained in the same year with Webb's Golden King and with Carter's 1901.

A plant which varies as much as the above figures indicate ought to be capable of rapid improvement by careful selection. Such an improvement has been brought about in the case of the sugar beet. About 50 years ago Ventzke suggested that sugar-beet workers were selecting for shape and other external characters, and neglecting the really important point, namely the sugar content. Very soon afterwards Vilmorin commenced selecting sugar beet for composition, his first method being to pick out for seed-mothers roots of high specific gravity. This method he soon changed, and began to select for high specific gravity of juice. About this time Anderson, whose paper has

been already quoted, proposed this method for selecting swedes. His figures are plotted on the annexed diagram (Fig. 4), which shows that high specific gravity of juice is by no means an accurate measure of percentage of dry matter. Scheibler in 1867 showed that specific gravity is not a reliable criterion for selection, as it is so greatly influenced by included air and other sources of error.

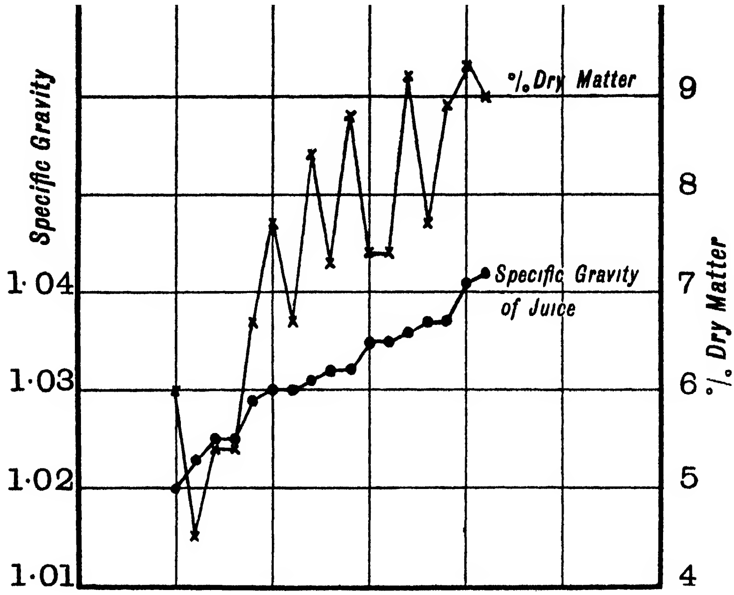

FIG. 4.
Plotted from Anderson's figures.

In 1867 Marek suggested that in selecting there should be an actual determination of the percentage of sugar in the juice by means of the polarimeter, and that, in order to increase the sugar without increasing the other solids of the juice, which interfere with the crystallisation of the sugar, the percentage of total solids in the juice should also be determined, and the sugar calculated as percentage of the total solids, or quotient of purity as it is called. The actual selection is then made for high percentage of sugar combined with high quotient of purity.

The above short outline of the development of the methods of sugar-beet selection is taken from Briem's *Der Praktische Rübenbau.* The success of this method of selection is shown by the following figures, which represent the average percentage of sugar in sugar-beet juice as calculated from figures found in the *Jahresbericht über Agricultur Chemie.*

Side by side with them are printed figures for the percentage of dry matter in mangels, similarly calculated except for the figure for 1852, which is taken from the tables of analyses in the *R.A.S.E. Journal* for that year.

SUGAR BEET				MANGELS			
Year	Sugar in Juice %	Year	Sugar in Juice %	Year	Dry Matter %	Year	Dry Matter %
1860–61	10·93	1882–83	13·60	1852	11·5	1895–1900	11·80
1868–69	11·34	1885	14·00	1880–84	10·97	1902	12·9
1870–72	11·80	1886	15·00	1885–89	11·78	1903	11·8
1873–74	12·65	1889	15·04	1890–94	13·04	1904	12·3

These figures bring out several important points. For instance, the steady improvement of the sugar beet from about 1870, when chemical selection was established on a satisfactory basis, is very apparent, and contrasts markedly with the constancy in the composition of mangels during the last 50 years.

The sugar beet has been selected for a definite purpose, and great improvement for that purpose has been brought about. The mangel has been selected also, but selection has been made for such external characters as shape, colour, size, rather than for improved chemical composition. The result is that we now have many strains of improved shape, colour, size, and so on, but the average percentage of dry matter remains much as it was 50 years ago.

The question now arises—is it possible to improve the mangel in quality, and if so, how must selection be carried out?

The first point is to decide what particular quality we want to improve. Mangels are grown almost entirely for food for cattle and sheep, and unfortunately there is very little definite information to be found as to the feeding value of the separate constituents of roots. In Danish experiments, carried out with pigs in 1895–8, the feeding value of roots was found to depend practically on the percentage of total dry matter[1], and the same result was arrived at in experiments at Cockle Park in 1902–3[2]. It would appear therefore that selection for high

[1] *Report of Royal Vet. and Agr. Lab. Copenhagen*, 1899. Quoted from *Expt. Stn. Record*, xi. p. 68.

[2] *Seventh Annual Report, Northumberland Demonstration Farm.*

content of dry matter would probably improve the feeding quality, and we have already commenced selecting in this direction as an experiment.

The feeding value of the various constituents of roots seems to need further investigation, and the University Department of Agriculture has experiments already in progress which it is hoped will throw more light on the subject. In the meantime, since selection can only be made in those directions in which variation occurs, we have studied the individual variation of several characters such as percentages of dry matter, sugar, and nitrogen, selection for which might bring about improvement, and colour, shape, specific gravity of juice, which might be correlated with some useful character, and which might therefore aid in selecting.

The annexed diagram (Fig. 5) shows the variation among 100 individual roots of a strain of Yellow-fleshed Globe, all grown side by side at the University Farm in 1903. They are plotted in ascending order of dry matter per cent., and the points marked on the same vertical line give the following characters from the top of the diagram downwards: Weight of root in lbs.; percentage, in the root, of dry matter and sugar; specific gravity of the juice; colour of the juice after clarifying with basic lead acetate; percentage in the root of total nitrogen $\times$ 6·25, and of proteid nitrogen $\times$ 6·25.

The dry matter was determined by drying a vertical sector representing about a quarter of the root; the sugar by polarising the juice before and after inversion, and correcting by the factor ·93 (see p. 184); the colour by comparing with arbitrary standards in a Lovibond tintometer; the total nitrogen by Kjeldahl's method in the dry matter; and the proteid nitrogen by the copper acetate method in the dry matter.

Examination of the diagram shows at once a great variation in percentage of dry matter—from 8·8 to 15·5 per cent.—and the curve shows all the usual features of a variation curve, a few very bad individuals, a few very good, and the rest intermediate.

The relation of the characters to each other is not very clear, and it will be necessary to consider them in detail.

Dry matter and weight. Following the curves for these two characters across the diagram, it is seen that on the whole there is a tendency for the weight of the root to fall as the dry matter rises, and this is what we should expect from the figures given on p. 186, but it is also evident that, while 50 large roots will always contain a lower percentage of dry matter than 50 small ones grown under the same conditions, yet it is by no means true that every large root is low in dry matter. Several

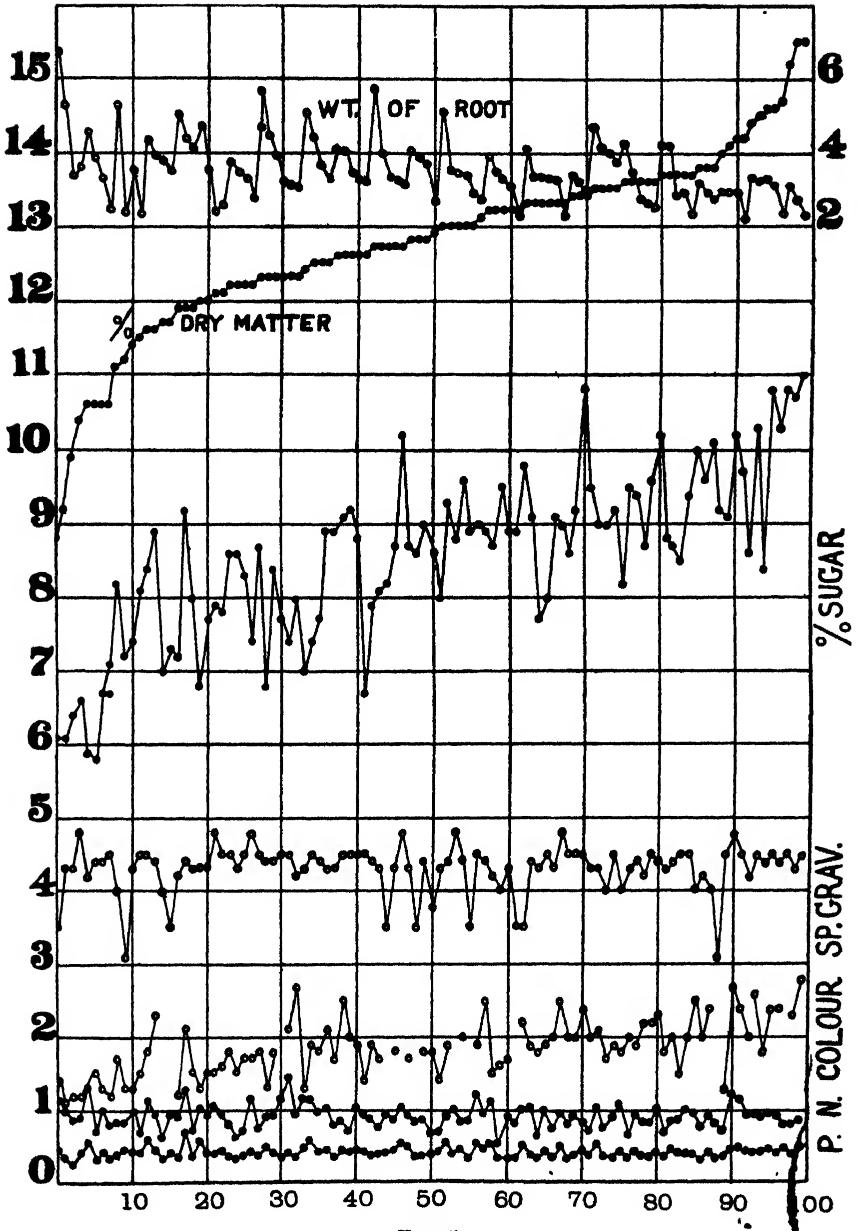

FIG. 5.

P = proteid Nitrogen °/ₒ × 6·25.
N = total Nitrogen °/ₒ × 6·25.

averaged 12·9 per cent. dry matter, 18 which approximated more nearly to the tankard shape averaged 12·8 per cent., and 18 which were what may be called heart shaped also averaged 12·8 per cent., so that shape does not appear to have any definite connexion with percentage of dry matter.

It appears therefore that in the present state of our knowledge the method of selection most likely to result in improvement in the feeding value of mangels is selection for high percentage of dry matter, and that in making this selection reliance must not be placed on shape, colour, or specific gravity of juice, but the dry matter in each individual root must be actually determined.

We have already shown that the coring method of sampling gives reliable results for dry matter in samples taken from at least 50 roots. Obviously this is the only method which can be used for selecting, since any other method, such as the sector method, would damage the root too much for future seed growing. It is therefore necessary to test the coring method for single roots, and we have done this in the case of the 100 roots which were examined for individual variation. Before removing the sector a horizontal core was taken through the greatest diameter of the root, and both the core and the sector were dried side by side. The annexed diagram (Fig. 6) shows the results of the two series of determinations. It is evident that coring does not give entirely satisfactory results, especially with roots containing low percentages of dry matter, where the difference from the sector method occasionally amounts to as much as 1 per cent. For the higher percentages the two methods agree much more closely; thus the average error of the whole series is ·46 per cent., of the 50 roots lowest in dry matter ·51 per cent, and of the 50 highest in dry matter ·40 per cent.

An error of such magnitude might prevent the selection of the root highest in dry matter, but with a range of variation of between 7 and 8 per cent., the method would still be good enough to ensure the selection of roots which were certainly very much above the average.

There are several obvious sources of error in the method, as for instance the squeezing out of a little juice from the core on account of the narrowness and lack of uniformity of bore of the coring instrument. These we are endeavouring to remove, and we hope to improve the method considerably.

In the meantime we have already made a commencement, and have grown one crop of mangels and one of swedes from seed grown from mother-roots selected for high dry matter. The individuals of this

crop are at present under examination for the selection of mother-roots from which to grow seed for a second selection. The accompanying diagrams (Figs. 7 and 8) show the results of the analyses from which the first selection was made. They are reprinted from our preliminary paper in the *Proceedings of the Cambridge Philosophical Society* already referred to.

The curves in the above diagrams show very great variation in content of dry matter among individual roots of mangels of several strains.

Roots of mangels and swedes selected from the individuals whose composition is given in the diagrams were planted in the spring of 1903, and seed was obtained from them in the autumn of that year. The amount and quality of the seed was, however, very poor, on account of the extreme wetness and coldness of the summer and autumn, and the drought in the spring and early summer of 1904 also militated against the successful germination of what little seed we had to sow. Consequently the crop of 1904 was but a poor one. It is at the present time under examination for the selection of seed-mothers for a second generation.

In conclusion, we desire to express our thanks to Professor Middleton, who has always been ready to help us with advice on all practical points, and has grown material for us on the University Farm; to Messrs Garrett Taylor of Trowse, B. B. Sapwell of Aylsham, Shepherd Cross of Hamels Park, T. Goodchild of Yeldham, B. D. Wood of Field Dalling, E. Druce of the Bedford County Institute, and Major White of Saxlingham, who have grown mangels for us on their farms; to Messrs H. Giles, H. Henshaw, J. Goodchild, B.A., and R. W. B. C. Wood, B.A., who have supervised the sowing, harvesting, and sampling of the roots; and to our senior students, Messrs W. Cartwright, B.A., S. F. Harwood, B A., and E. F. A. Swann, who have helped us on many occasions when samples arrived faster than we could deal with them. We would also acknowledge our indebtedness to Mr A. D. Hall, M.A., for information about the Rothamsted mangel experiments, to Dr Sigmund Stein for particulars of the sugar-beet industry, and to Mr P. Hedworth Foulkes of the Harper-Adams College for information about the mangel experiments carried out by that institution.

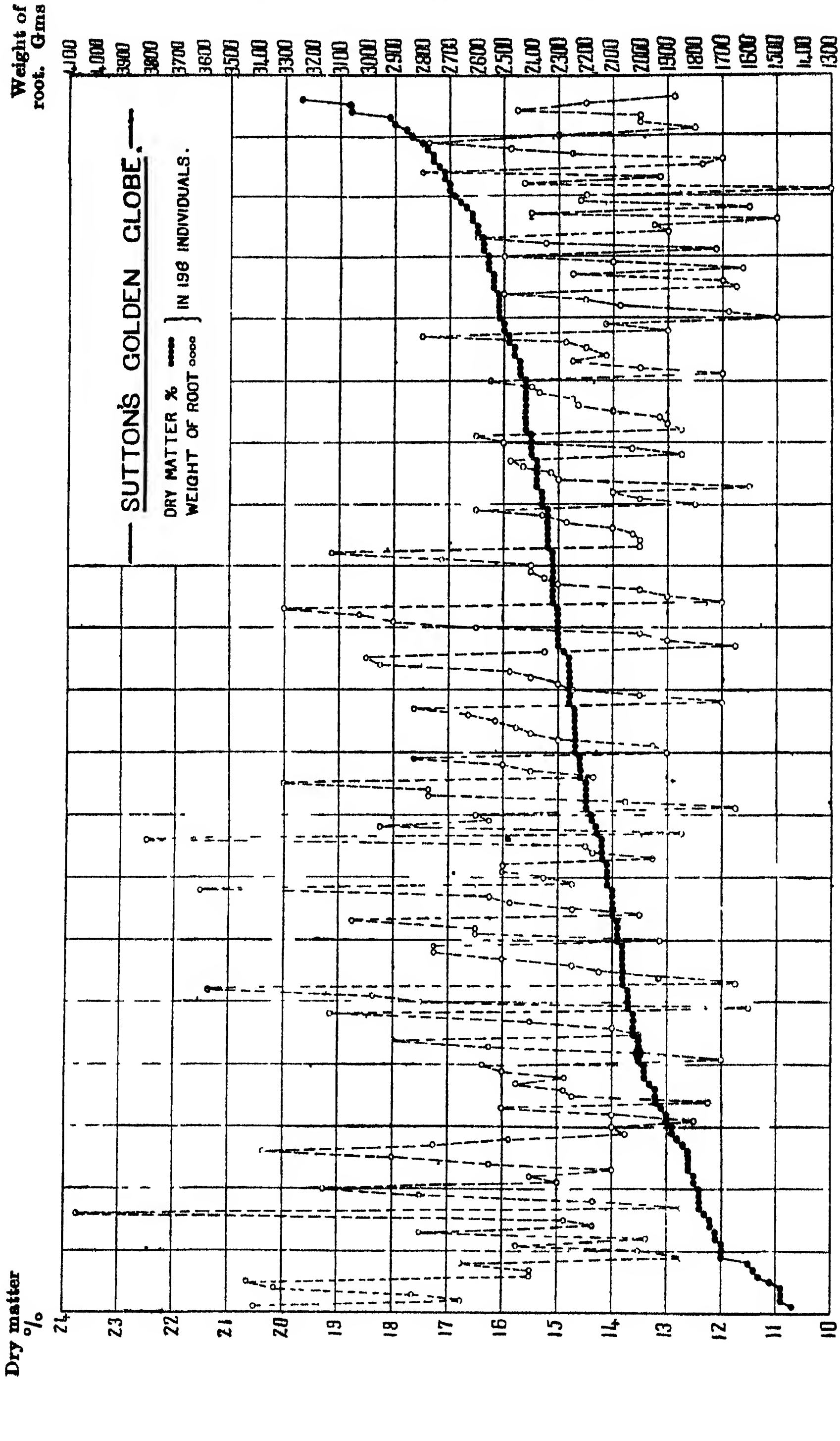
Weight of root. Gms
Dry matter %
SUTTON'S GOLDEN GLOBE.
DRY MATTER %
WEIGHT OF ROOT
IN 198 INDIVIDUALS.

Fig. 7.

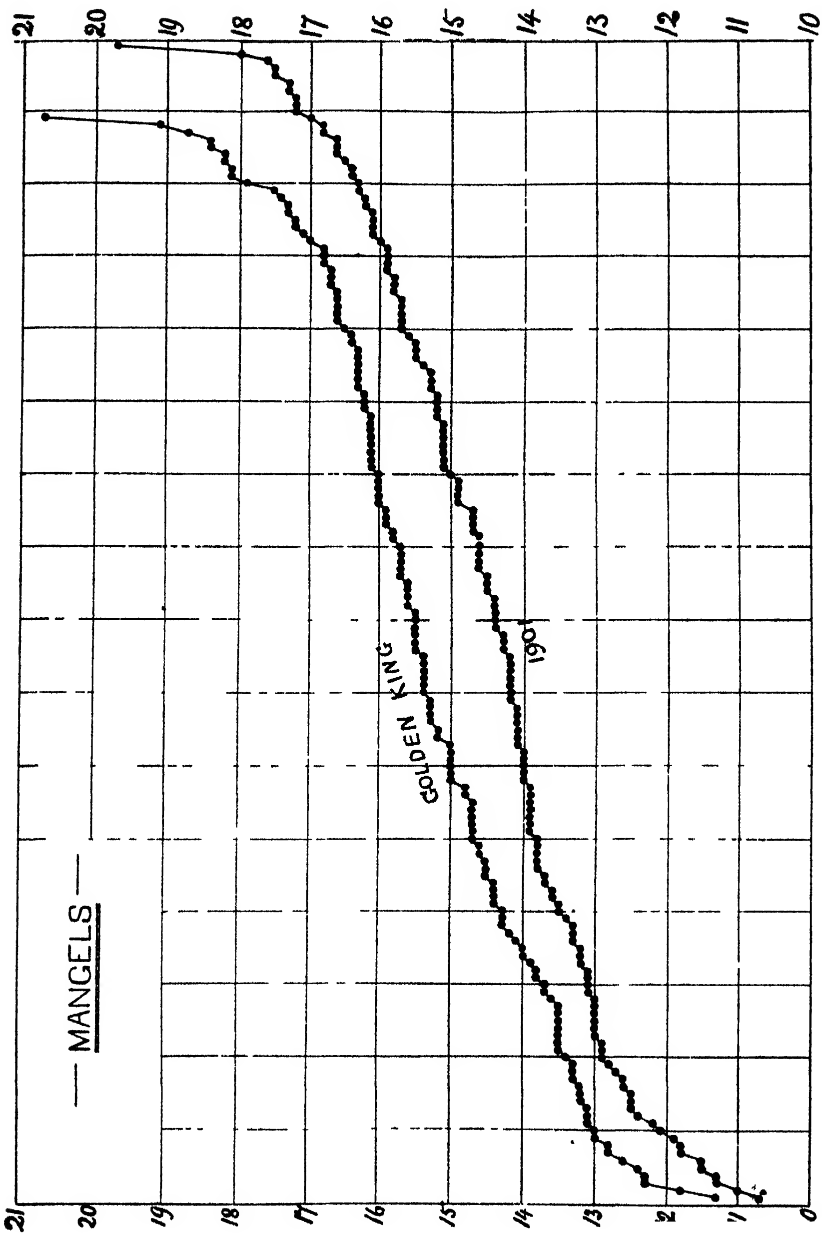

FIG. 8.

Summary.

Below is a brief summary of the chief points of interest which our investigations appear to have suggested so far:

That the most convenient method of sampling roots for analysis is to remove a core from each root, and that when using this method at least 50 roots must be cored in order to obtain a sample representing the composition of the bulk of roots grown on a field.

That a large proportion of the commonly grown strains of mangels may be assigned to one or other of five types.

That of these types, four have their cropping power and percentage of dry matter so nearly in inverse proportion that they yield practically the same weight of dry matter per acre.

That the fifth type, Long Red, yields considerably more dry matter per acre than the other four varieties.

That large roots on the average contain more water and less dry matter than smaller ones.

That there is a considerable variation in the composition of mangels from year to year, probably depending on such conditions as rainfall and sunshine at particular periods of growth.

That manurial treatment causes distinct variations in composition, the most noticeable point being that excessive applications of nitrogen delay ripening and decrease the percentage of dry matter.

That different farms grow roots of different composition.

That there is very great variation among individual roots of the same variety grown side by side, in content of dry matter, sugar, and nitrogen, and in size, shape, colour; in fact, in all the characters which we have been able to observe.

That there is so little correlation between the different characters that it is possible to pick out for seed-mothers large roots containing high percentages of dry matter rich in any desired constituent, and it is suggested that, from analogy with the sugar beet, continuous selection carried out in this manner may result in improvement in any desired direction.

That since colour, shape, and specific gravity of root or of juice are shown not to be correlated with percentage of dry matter, sugar, or nitrogen, selection for these characters is not likely to lead to any improvement.

THE INFLUENCE OF SULPHATES AS MANURE UPON THE YIELD AND FEEDING VALUE OF CROPS.

By T. S. DYMOND, F.I.C., F. HUGHES, AND C. W. C. JUPE.

An agricultural problem to which little attention has been directed is the relation of the supply of combined sulphuric acid in the soil to the growth of crops. Field experiments upon the value of gypsum and sulphate of iron have been made, and artificial manures containing sulphates are constantly being used, but the specific effect of the combined sulphuric acid in these materials seems never to have been sufficiently investigated. Indeed, any useful effect produced by gypsum has been ascribed to indirect action, *e.g.*, the liberation of other constituents from insoluble soil compounds.

Yet sulphur is an essential element for plants, and takes as important a position as phosphorus in their quantitative composition. According to published analyses the following crops contain in lbs. per acre:—

	Sulphur	Phosphorus		Sulphur	Phosphorus
Barley	6·1	9·0	Vetches	3·9	5·6
Oats	8·0	8·4	Beans	9·3	12·7
Maize .. .	3·8	7·9	Swedes	17·8	9·9
Meadow hay	5·7	5·3	Cabbages .	32·9	25·3
Red clover .	9·4	10·9	AVERAGE.	10·8	10·6

The yield of a crop is likely to depend as much upon a sufficiency of available sulphuric acid as upon that of phosphoric acid in the soil, and to constitute a sufficiency, as the foregoing figures shew, more of the former will be often required than of the latter.

There is also another question involved. Sulphur is an invariable constituent of the albuminoids found in crops, and, unless it can be

shown that sulphur can be replaced by oxygen in these compounds, a sufficiency of combined sulphuric acid in the plant food is necessary to the formation of a high percentage of albuminoid. It is therefore not only a question of yield, but also of feeding value. We will first discuss the supply of combined sulphuric acid in the soil and its influence on the yield of crops, and afterwards its relation to feeding value.

In south-east Essex, the existence of sulphates in clay soils is often manifest. On a dry bank under a hedge a white efflorescence of gypsum may frequently be observed. On a bright day after rain the soil of a field will become "capped" with the same substance. In superficial layers of the London clay star-shaped clusters of selenite crystals are often found. Surface-well waters in the same district contain enormous quantities of the sulphates of calcium and magnesium, the latter predominating. One such water from Wickford that we examined had a permanent hardness equal to 93 parts of calcium sulphate per 100,000, and another from Ingrave as much as 112 parts. Rudler suggests that the source of the calcium sulphate is oxidation of the pyrites in the London clay, and reaction of the resulting sulphuric acid with fossils and septaria. It might however be due to the reaction of the sulphuric acid of rain with the calcium carbonate of the surface soil, for the London clay, being almost impermeable, prevents the draining away of the sulphate formed and the solution becomes more concentrated by evaporation. Even a permeable subsoil may contain more combined sulphuric acid than the surface soil. Thus a boulder clay subsoil at Cressing was found to contain 0·055 per cent. sulphuric acid (SO_3), the top soil only 0·028.

A number of Essex soils have been analysed for sulphuric acid. The following table gives the results compared with phosphoric acid, the numbers representing the percentage extracted by strong acid from the fine earth, air-dried, from the top nine inches of soil.

It will be seen that the combined sulphuric acid in Essex soils is very small and is always less than, and averages two-fifths of, the phosphoric acid. It will be suggested that the reason why these soils, though notoriously deficient in phosphoric acid, are not supposed to be deficient in sulphuric acid is that the latter is mostly in an available state. This is not the case; the soil from Gt. Oakley extracted by a one per cent. solution of citric acid gave only 0·006 per cent. "available" sulphuric acid. It must be supposed that the greater part of the sulphuric acid is in the form of insoluble basic sulphates of

aluminium, etc. The small amount of available sulphuric acid in these soils is accounted for by its loss by drainage, sulphates being always one of the most abundant constituents of drainage waters. The sulphuric acid lost by drainage in the 20 inch drain gauge in the Barn Field at Rothamsted was found in 1896 to amount to 71·4 lbs. per acre[1], which would mean a loss to the soil of ·001 per cent.

Percentage of Sulphuric and Phosphoric Acids in Essex Soils.

Locality	Sulphuric Acid. SO_3	Phosphoric Acid. P_2O_5	Locality	Sulphuric Acid. SO_3	Phosphoric Acid. P_2O_5
Birch*	0·038	0·120	Orsett	0·050	0·080
Bromley	0·062	0·250	Great Oakley*	0·048	0·100
Bulphan*	0·030	0·100	Ramsden*	0·080	0·220
Burnham	0·080	0·180	Saffron Walden (1)	0·093	0·110
Cressing	0·028	0·060	,, (2)	0·079	0·090
Dunton*	0·028	0·140	St Osyth	0·043	0·090
Elmstead	0·043	0·080	Tendring (1)	0·035	0·060
Gosfield	0·060	0·240	,, (2)*	0·050	0·160
Margaretting	0·056	0·160	Thaxted (1)	0·040	0·130
Mucking	0·029	0·120	,, (2)	0·045	0·150
North Ockendon	0·039	0·170	AVERAGE	0·051	0·134

* These soils overlie London clay subsoils.

As these analyses point clearly to possible deficiency of sulphuric acid in a state available for crops, some experiments were carried out for the Essex Education Committee in 1896 and the following years upon the specific value of combined sulphuric acid in manures. A difficulty experienced in the experiment was the necessity of eliminating the effect of the base with which the sulphuric acid is combined. On chalky soils the effect of gypsum against no gypsum could be compared, but this was inadmissible on other soils because the lime of the gypsum would exert its own specific physical or chemical influence. On such non-chalky soils sulphate of ammonium as against chloride of ammonium was ultimately used, but the plan is not without objections, for of the sulphuric and hydrochloric acids liberated by nitrification in the soil, the latter will have greater activity in liberating other food materials from feebly soluble compounds owing to its greater ionisation in solution, besides which the formation of calcium and magnesium chlorides, as against sulphates, will render the soil more hygroscopic,

[1] From figures supplied by Mr A. D. Hall.

MANURIAL EXPERIMENTS WITH SULPHATES.

Manures used and Produce in quantities per Acre.

A. With Muriate and Sulphate of Ammonia.

		Muriate of Ammonia, 176 lbs.		Sulphate of Ammonia, 224 lbs		Increase or Decrease due to Sulphate	
PERMANENT PASTURE—		Hay in cwt.		Hay in cwt.		Hay in cwt.	
At the Hall Farm, Bulphan. Subsoil, London clay. The sulphate and muriate were applied each year. No other manure used. The grass was grazed in 1900.	1896	27·1		25·5		−1·6	
	1897	49·4		51·5		+2·1	
	1898	35·5		31·9		−3·6	
	1899	19·3		18·6		−0·7	
	1901	9·9		13·6		+3·7	
	Mean	28·2		28·2		0·0	
OATS—		Corn in bushels	Straw in cwt.	Corn in bushels	Straw in cwt.	Corn in bushels	Straw in cwt.
At Frith's Farm, Great Oakley. Subsoil, London clay. Ten loads dung ploughed in just before sowing.	1896	50·4	19·3	45·6	16·3	−4·8	−3·0
BARLEY—							
On another part of the same field following the oats.	1897	46·3	25·7	44·6	24·4	−1·7	−1·3
CABBAGES—		Tons : cwt		Tons : cwt.		Tons : cwt.	
At Bearman's Farm, Margaretting. Subsoil, boulder clay. The cabbages were grown on a different field each year, and in each case the land was dressed with dung.	1896	19 : 1·6		20 : 15·5		+1 : 13·9	
	1897	11 : 13·2		12 : 13·5		+1 : 0·3	
	1898	14 : 2·5		14 : 6·7		+0 : 4·2	
	Mean	14 : 12·4		15 : 11·9		+0 : 19·5	

		Tons : cwt.		Tons : cwt.		Tons : cwt.	
SWEDES—							
At Church Farm, Feering. Subsoil, boulder clay.	1898	5 : 15·4		5 : 11·1		−0 : 4·3	

B. WITH AND WITHOUT SULPHATE OF LIME.

		No Sulphate		Sulphate of Lime 2 cwts.		Increase or Decrease due to Sulphate	
OATS—		Corn and Straw in cwt.		Corn and Straw in cwt.		Corn and Straw in cwt.	
At Lt. Boynton Hall, Roxwell. Subsoil, boulder clay.	1896	32·0		32·1		+0·1	
PEAS—		Corn in bushels	Straw in cwt.	Corn in bushels	Straw in cwt.	Corn in bushels	Straw in cwt.
At Newhouse Farm, Cressing. Subsoil, boulder clay. The peas were dressed with Webb's pea manure containing sulphate.	1896	7·6		6·5	...	−1·1	...
At Old Wills Farm, Feering. Subsoil, boulder clay. The peas were dressed with 1¼ cwt. nitrogenous guano (free from sulphate).	1898	34·5	21·8	35·4	22·1	+0·9	+0·3
RED CLOVER—		Hay in cwt.		Hay in cwt.		Hay in cwt.	
At Newhouse Farm, Cressing. Subsoil, boulder clay. The clover was dressed with farmyard manure.	1897	51·7		62·2		+11·5	

and, in dry seasons such as those during which the experiments were carried out, be certain to affect the luxuriance of the crops to some extent.

The results of the experiments are given in the tables[1] on pp. 220 and 221.

These results indicate very clearly the kind of crops that will be increased by the application of combined sulphuric acid in manures, viz. a heavy yielding crop rich in albuminoid. The oats and barley being comparatively poor in albuminoid were not benefited by sulphate manuring, indeed in the case of those grown at Gt. Oakley the chloride had a more beneficial action,—this being due either to its greater activity as a solvent or to its hygroscopic action in the soil during two dry seasons. The swedes, although a crop rich in combined sulphur, are poor in albuminoid, and were not benefited by sulphate manuring, partly however because the yield was so small. Cabbages, a crop which is richer in albuminoid and gives a very heavy yield, were benefited in each of the three seasons the experiment was made. Red clover, also yielding heavily and rich in albuminoid, was increased to the extent of 20 per cent. by sulphate manuring. Permanent pasture gave, on the average of five seasons' crops, precisely the same yield of hay with sulphate as with chloride of ammonium, for neither were the crops heavy nor is the percentage of albuminoid in hay high; but as might have been expected it was found that, in the year that the herbage was analysed (1897), the sulphates had had some influence upon maintaining the clover against the injurious influence of the nitrogen of the manure:—

Clover on the unmanured plot .	= 32·4	per cent.
„ „ sulphate of ammonium	= 12·6	„
„ „ chloride of ammonium	= 8·6	„

Peas, a crop containing more than an average amount of albuminoid, were slightly benefited when the yield was heavy, but actually injured when the crop was light and an excessive quantity of sulphate employed. That an excessive quantity of sulphate is injurious to crops

[1] For carrying out these experiments the Committee were indebted to Mr Harry Mann, Bulphan, Mr Percy Stanford, Great Oakley, Mr George McMillan, Margaretting, Mr R. W. Christy, Roxwell, Mr J. W. Moss, Feering, Mr Philip Hutley, Witham and Cressing, and Mr J. W. Hepburn. In the tables the names under which the manures are known in commerce are used,—muriate and sulphate of ammonia for ammonium chloride and sulphate, and sulphate of lime for calcium sulphate (gypsum).

seems to be the case, probably owing to its action on the physical condition of the soil. Other field experiments in Essex have shewn the deleterious effect of too large a dressing of superphosphate of lime on mangolds, even on chalky soils, and this is likely to be due to the large quantity of sulphate thus applied. In mixing manures the desirability of limiting the sulphates employed should be remembered, for a mixture of superphosphate, sulphate of ammonia and sulphate of potash, especially when sulphate of lime is added to improve the condition of the manure for sowing, must almost certainly contain an injurious proportion.

As these field experiments demonstrate that the usefulness of sulphate manuring is generally confined to heavy yielding crops containing a high proportion of albuminoid, it remains to be considered why soils so poor in available sulphate still contain sufficient for other crops, whereas the available phosphate is insufficient, although both are required by these crops in nearly equal amount. The two possible sources of supply of sulphuric acid during the growth of a crop are (1) organic sulphur compounds of the soil, and (2) rain. Each of these must be considered.

Berthelot and André[1] have shewn that in addition to the sulphates dissolved by hydrochloric acid and precipitable by barium chloride, sulphur exists in the soil in the form of ethereal sulphates, metallic sulphides, and organic nitrogen compounds of sulphur. The only method of estimating the total sulphur is therefore by combustion, the gaseous products being passed over heated sodium carbonate. By this method they obtained an amount of sulphur nearly eight times as great as that present in the soil in the form of metallic sulphates. This is probably in excess of the proportion found in soils so poor in organic matter as those of Essex; still it is important to enquire to what extent any store of combined sulphur in our own soil can be utilized by oxidation to sulphuric acid.

To investigate this question two glass tubes were filled with a London clay soil (from Birch), both sufficiently moist. Each was sterilized by heating at 100° for an hour and a-half on two consecutive days. One of the two soils was then inoculated with the washings from a little fresh soil. Sterilized air was then passed through each tube for 70 hours at the rate of three litres an hour. Each soil was finally extracted with hydrochloric acid and the sulphuric acid deter-

[1] *Ann. de Chim. et de Phys.* T. 15, p. 119.

mined. The sterile soil was found to contain 0·026 per cent. sulphuric acid, the inoculated soil 0·034 per cent., an increase of 0·008 per cent. by oxidation due to bacterial action[1]. It is therefore clear that the percentage of sulphuric acid extracted from a soil by hydrochloric acid no more represents the supply available for a crop during its whole period of growth, than the percentage of nitric acid represents the available nitrogen.

We turn now to the question of the supply of sulphuric acid in rain. A sample of rain-water collected at this laboratory gave on analysis 1 part of sulphuric acid per 100,000, which for the average annual rainfall between 1895—1903 (= 500,000 gallons per acre) amounts to 50 lbs. per acre, a quantity sufficient for the heaviest crops! But this is greater than that in purely rural districts. The sulphuric acid collected in the small rain gauge at Rothamsted equals 18·5 lbs. per acre[2], a quantity sufficient for cereal crops and permanent pasture, but not for heavy crops of roots or clover. Of course on arable land a considerable part of this will be lost by drainage, but on permanent pasture the quantity is such as to provide for storage of combined sulphur taking place, so that tillage crops may have sulphuric acid produced by the gradual oxidation of the organic compounds stored in previous years when the land was under grass, as well as the sulphuric acid of rain, to depend upon

Evidence of the sufficiency of the supply of sulphuric acid by rain for most crops, where loss by drainage was prevented, was obtained by a series of pot cultures, the results of which are given in the accompanying table. The sand for the cultures of maize and clover was washed with distilled water till practically free from soluble sulphate. Analysis shewed that it still contained 0·00075 per cent. total sulphuric acid, which amounted to 0·1 gram for the whole pot full of sand (32 lbs.). The sand used in other cultures was probably still more free, as it was first washed with hydrochloric acid and then with distilled water till free from acid. The soils used were obtained from Mucking and from Cressing, and contained 0·028 and 0·029 per cent. of sulphuric acid respectively. Each pot was manured with 5 grams calcium carbonate and 1 gram magnesium carbonate, mixed into the sand or soil, and a solution was applied in small portions from time to time containing 5 grams potassium nitrate and 2 grams

[1] For an account of sulphur bacteria see Conn's *Agricultural Bacteriology*, p. 59.

[2] From figures supplied by Mr A. D. Hall.

of ammonium phosphate. The sulphate pots received 2 grams of gypsum along with the calcium and magnesium carbonate.

Yield of Crops grown in Sand and Soil.

Crop	Grown in	Manured with	Produce as gathered in grams.	Dried at 100° in grams.
Vetches	Sand	Gypsum	38	17*
,,	,,	No Gypsum	33	13*
,,	Soil	Gypsum	166	30
,,	,,	No Gypsum	146	27
Oats (Corn and Straw)	Sand	Gypsum	14	8
,, ,, ,,	,,	No Gypsum	22	13
,, ,, ,,	Soil	Gypsum	44	23
,, ,, ,,	,,	No Gypsum	51	26
Mustard	Sand	Gypsum	9	5
,,	,,	No Gypsum	9	5
,,	Soil	Gypsum	28	13
,,	,,	No Gypsum	37	18
Onions	Sand	Gypsum	8	†
,,	,,	No Gypsum	31	†
,,	Soil	Gypsum	285	†
,,	,,	No Gypsum	358	†
Maize	Sand	Gypsum	437	73‡
,,	,,	No Gypsum	155	22§
Red Clover	,,	Gypsum	49	†
,,	,,	No Gypsum	20	†

* Including roots.
† Not determined.
‡ Weighed 101 grams, including roots.
§ Weighed 84 grams, including roots.

While the pots of vetches, oats, mustard, and onions were exposed to rain, the pots of maize and clover were protected. It is in these last two series only that manuring with sulphate produced any visible increase in the crops. Of the other four series, the oats, mustard, and onions, far from being increased by the application of sulphate, were decreased, and of the crops exposed to rain the vetches alone shewed an increase. The reason for this is probably partly due to the vetches being the crops richest in proteids and requiring more sulphur in consequence for development, but chiefly to the injurious effect of the sulphate, in the case of the oats, mustard, and onions, in causing bad physical condition of the sand and soil by "capping" the surface, and thus both limiting aëration and increasing evaporation of water; the vetches, on the other hand, being a covering crop, prevented the capping from taking place. The general result of the pot cultures is

to confirm the lesson of the field experiments, that it is only in the case of heavy yielding crops, rich in albuminoid, that useful results from sulphate manuring can be looked for, and that a large excess of sulphate is injurious owing to physical action on the soil.

Influence on Feeding Value. The object of this part of the investigation was to ascertain whether, since the albuminoid of crops contains sulphur compounds, the proportion of albuminoid, and therefore the feeding value, is increased by manuring with combined sulphuric acid. For the purpose of this enquiry, the pot-grown crops already described, and the grasses and red clover separated from the 1897 herbage of the Bulphan plots were used for analysis, together with some specimens from the experimental plots at Rothamsted kindly supplied by Mr A. D. Hall. Total nitrogen was determined by Kjeldahl's method, albuminoid nitrogen by Stützer's method, and total sulphur by the combustion method (see above). Several duplicate determinations were made, and the authors are satisfied that the analytical methods gave comparable results. The results of the analyses are given in the accompanying table.

The figures shew that manuring with sulphate has always increased the percentage of total sulphur in the crops. In every case but two it also increased the percentage of total nitrogen, and in every case but one the percentage of albuminoid nitrogen The albuminoid nitrogen per cent. of total nitrogen is sometimes increased, but not always, so that the series appears at first sight to be inconclusive.

But the result of the analyses of the pot-grown crops must be considered in connexion with the yield (see p. 225). In several cases the application of sulphate, by producing an unfavourable condition in the sand or soil, checked plant development. The result would be the increase of the percentage of nitrogen, independently of any absorption of sulphate as plant food, and the probable increase of the percentage of albuminoid owing to the earlier maturity of the crop. Any conclusion must therefore be drawn only from the two pot cultures in which this source of error does not occur, viz. vetches grown in sand and soil and maize grown in sand.

In the case of the vetches, the pots were not protected from rain, and even those not manured with sulphate had therefore a considerable though insufficient supply. That the further application of sulphate increased the percentage of albuminoid as well as the total weight of the crop appears to be conclusive evidence that albuminoid formation is directly dependent on a sufficient supply of sulphate. The increased

absorption and percentage of total nitrogen is the natural result of the formation and storage of albuminoid.

Percentage of Nitrogen and Sulphur in Crops (dried at 100°) *grown in sand and soil in Pots and also in the Field.*

Crop	Grown in	Manured with	Total S.	Total N.	Alb. N.	Alb. N. % of Total N.
Vetches	Sand	Gypsum	*	3·07	2·27	74
,,	,,	No Gypsum	*	3·00	2·00	67
,,	Soil	Gypsum	0·47	3·44	2·61	76
,,	,,	No Gypsum	0·39	3·16	2·21	70
Oats (Corn & Straw)	Sand	Gypsum	*	0·92	0·50	54
,, ,, ,,	,,	No Gypsum	*	0·87	0·46	53
,, ,, ,,	Soil	Gypsum	0·33	1·50	0·77	51
,, ,, ,,	,,	No Gypsum	0·32	1·47	0·75	51
Mustard	Sand	Gypsum	*	1·55	0·57	37
,,	,,	No Gypsum	*	1·49	0·55	37
,,	Soil	Gypsum	0·63	1·75	0·79	45
,,	,,	No Gypsum	0·50	1·60	0·76	47
Maize	Sand	Gypsum	0·39	1·19	0·98	83
,,	,,	No Gypsum	0·23	2·28	0·83	36
Red Clover	Field	$(NH_4)_2SO_4$	0·36	2·63	1·96	73
,,	,,	NH_4Cl	0·32	2·09	1·79	86
Grass	,,	$(NH_4)_2SO_4$	0·24	1·31	0·98	75
,,	,,	NH_4Cl	0·15	1·06	0·84	79
Wheat (grain)	,,	$(NH_4)_2SO_4$ & NH_4Cl	—	0·91	0·83	91
,, ,,	,,	Rape cake	—	0·89	0·82	92
Barley (grain)	,,	$(NH_4)_2SO_4$ & NH_4Cl	—	0·40	0·32	80
,, ,,	,,	$NaNO_3$	—	0·43	0·37	87

* Quantity of material insufficient for analysis.

In the case of the maize, the crop not receiving sulphate suffered from sulphate starvation to so great an extent that not only the production of albuminoid but also that of carbohydrate was greatly checked. The result was a high percentage of non-albuminoid nitrogen. In the crop receiving sulphate not only was plant development and production of carbohydrate and albuminoid enormously increased, but the percentage of albuminoid and therefore the feeding value was increased also.

By a combination of Stützer's and the combustion methods an attempt was made to determine whether the albuminoid sulphur was proportional to the albuminoid, as otherwise it might be objected that

sulphur not being essential to the composition of albuminoid the formation of albuminoid could not directly depend upon the supply of sulphate. The results were as follows:—

	Sulphate applied.	No sulphate applied.
Total sulphur . . .	0·39	0·23
Albuminoid sulphur . .	0·15	0·11
Albuminoid nitrogen . .	0·98	0·82
Ratio $\frac{\text{alb. nitrogen}}{\text{alb. sulphur}}$ . .	6·6	7·5

The two ratios are, within the limits of experimental error, almost in agreement, and at any rate shew that if the sulphur in albuminoid is replaceable by oxygen it is only to a very small extent.

The results of analyses of crops grown in the field do not entirely agree with those of the pot-grown vetches and maize. There is always however the disturbing influence of the substance used on the no-sulphate plot in the attempt to make it comparable with the sulphate plot, an influence which has been accentuated in the Rothamsted crops owing to the same manurial treatment having been extended over a great number of years. These results cannot therefore be held to upset the conclusions arrived at from the pot cultures.

Lastly, the question must be asked as to what are the changes in the percentage composition of a crop, associated with the increase in the percentage of albuminoid. The following analytical results, calculated on dry matter, were obtained.

	Grass from Bulphan		Vetches grown in Sand	
	With Sulphate	Without Sulphate	With Sulphate	Without Sulphate
Albuminoids	6·12	5·25	14·19	12·50
Amides, etc.	2·06	1·37	5·00	6·25
Sol. Carbohydrates.	52·09	50·56	50·49	49·47
Fibre	32·40	35·60	25·30	27·10
Oil	1·02	0·92	1·55	1·28
Ash	6·31	6·30	3·47	3·40

These results seem to point to the production of albuminoid being associated with the storage of other reserve material. One of us is preparing to continue the study of this subject from a biological point of view.

To sum up the general conclusions of this enquiry:—

There is not sufficient sulphuric acid in the soil or supplied by rain for heavy yielding crops rich in albuminoid, either for the production of greatest yield or the highest feeding value, and for such crops a sulphate should be included in the artificial manure. For cereal crops and for permanent pasture the soil and rain provide all the sulphuric acid necessary.

COUNTY TECHNICAL LABORATORIES,
CHELMSFORD,
February 4th, 1905.

"BLACK-QUARTER" IN SHEEP.

By T. W. CAVE, F.R.C.V.S.,

Professor of Veterinary Science in the South-Eastern Agricultural College, Wye, Kent.

At the beginning of 1902 I was asked to investigate the nature and causation of a disease of sheep, locally termed "struck," with the hope of finding some suitable form of preventive treatment.

I was told that the mortality was very heavy, especially during March, April, and May, and that in one part of the Romney Marsh district a skin dealer had been known to collect 1400 or 1500 skins in a single week, practically the whole of which had been removed from "struck" sheep.

It was further stated as a well-known fact that with many Romney Marsh graziers the losses were equivalent to the death of their entire flocks, once every 16 or 17 years, from this cause alone. The disease was most common in Romney Marsh, but was also met with in other marsh-lands of Kent, and occasionally even in upland districts.

The term "struck" did not convey much meaning to me, a stranger to the locality, but I soon found that, although the term may be applied occasionally to any case of sudden death, yet there was one disease which was chiefly recognized under this name.

Various theories are held by the flock-owners of the district as to the true nature of the disease, some feared an investigation, lest the disease should be declared to be "anthrax," others described it as "acute indigestion" and "hoven," and blamed the young grass of spring-time as the cause. It is also spoken of as "inflammation of the bowels," "apoplexy," &c., but the prevailing opinion seems to be that in some way the new growth of grass in the spring is responsible for the heavy mortality at this period.

The disease certainly is the cause of many deaths in March, April, and May, but sporadic cases occur at all seasons of the year.

Sheep of all ages are attacked, but it is generally said that the best animals in the flock are most likely to suffer.

Soon after my enquiry was begun Mr C. Gillard, M.R.C.V.S., of Ashford, gave me the opportunity of seeing several cases in in-lamb ewes which were said to be "struck." As the outbreak proved to be of a severe character, 60 ewes dying in a few weeks out of a flock of 200, a carcase was sent by Mr Gillard to Professor M'Fadyean, who declared that death was due to "black-quarter."

This outbreak occurred in a district at some elevation above sea-level, where the loss from "struck" sheep was said to be usually slight.

As it had been known for many years that sheep suffered from "black-quarter" in some parts of Great Britain (Steel's *Diseases of Sheep*), I determined to find out whether sheep in Romney Marsh, which were said to be "struck," showed any of the lesions of that disease.

On post-mortem examination of a "struck" sheep it is usual to find some portion of the body greatly swollen, and the skin of a dark purple colour. Well-marked crepitations are discovered on palpation of the swellings. The swellings are frequently found on the inside of the hind-limb, extending from the hock to the groin and even along the abdominal wall; in the fore-limb extending from the knee upwards to the shoulder, and the muscles of the neck and back.

On removal of the skin the swollen parts are seen to be black or dark red in colour, and the subcutaneous connective tissue and the muscles are saturated with a blood-stained fluid which rapidly drains away when an incision is made.

Bubbles of gas escape from the surface of the section, and a well-marked odour of sour milk is easily distinguished.

In the internal organs the chief lesions are congestion of the lungs and the presence of bloody serum in the pleural and peritoneal cavities. These lesions seem to be identical with those of "black-quarter."

On making a microscopical examination of the fluid squeezed from the diseased flesh numerous rod-like organisms with rounded ends are to be found. These bacilli closely resemble those of "black-quarter." They are also to be found in the blood and in the pleural and peritoneal fluids.

A "struck" sheep rarely shows signs of ill-health. Generally the sheep is found dead in the pasture, although it may have been seen

apparently in good health a short time earlier. Sometimes the animal is seen to stagger, to fall to the ground, and to die in a few minutes.

More rarely death is delayed for some hours, and the sheep is seen standing with its four feet close together, its back arched, and breathing rapidly. There may be a frothy, blood-stained discharge from the nostrils, and a blood-stained diarrhœa. The animal moves unwillingly, and when made to do so exhibits considerable stiffness of the limbs. Soon it falls to the ground and quickly dies.

Owing to the rapid onset of the disease and the suddenness of death it is very difficult to say whether any marked swellings are to be detected during life. The thickness of the wool also makes the detection of the swellings more difficult while the animal is alive.

I rarely had the opportunity of examining a "struck" sheep during life, but I was able to make a considerable number of post-mortem examinations, and I always found swellings present in some part of the body, and the bacilli of "black-quarter" were always present in the exudate from the diseased muscle.

As it was not possible for me to make a bacteriological examination at the College, I submitted a slide of the bacilli to Professor M'Fadyean, who identified the organism as the "bacillus of black-quarter."

At a later stage of the enquiry Dr Hamilton, of Aberdeen, visited Romney Marsh with me and examined several carcases of "struck" sheep, and afterwards made a careful bacteriological examination of fluids and tissues then obtained. He informed me that he "found a bacillus quite comparable with that of 'black-quarter,' although he was not as yet prepared to say that they were identical."

I also learned that some years ago the late Mr Alston Edgar, F.R.C.V.S., of Dartford, Kent, had declared that "struck" sheep died from "black-quarter."

In order to prove to the sheep-owners of the district that the disease was not due to any dietetic cause as was popularly supposed, I inoculated a healthy sheep with the serum obtained from the diseased muscle of a "struck" sheep. The fluid was injected deeply into the muscles of the thigh, and the sheep died within 12 to 14 hours after the inoculation. The inoculated sheep presented all the appearances of a "struck" sheep, and a microscopical examination of the exudate showed the presence of numerous bacilli of "black-quarter."

The conclusions I drew from my enquiry were that the term "struck" was chiefly used in reference to sheep which after death presented the lesions above described, that these lesions were identical

with those of "black-quarter" in cattle and sheep, that the "black-quarter" bacillus was invariably present, and that practically the whole of the annual loss from "struck" sheep was due to the presence of the bacillus of "black-quarter."

This bacillus is known to exist in the soil of certain pastures, usually in damp, low-lying situations. Its spores are most tenacious of life. They will resist heat and cold, dryness and moisture, and may remain dormant in the soil for many years.

It is probable that infection occurs through the digestive organs, but it has also been suggested that the spores may enter the body through small punctured wounds[1].

PREVENTIVE MEASURES SUGGESTED.

As soon as I became aware that the disease was identical with "black-quarter" in sheep, I endeavoured to find some means of prevention suitable to the districts in which heavy losses occurred annually.

First, it was pointed out that the usual method of dealing with the carcase of a "struck" sheep was conducive to the prevalence of "black-quarter."

Throughout the Romney Marsh district carcases are flayed and then allowed to lie unburied, to be gradually destroyed by decomposition, or to be eaten by dogs, poultry, rats, &c. In this way the organisms contained by the diseased carcases are allowed to return to the soil, where the spores may live for many years, retaining their power to produce "black-quarter" when again introduced into the body of a living sheep.

Much benefit might be derived in a few years from the general and uniform adoption of some plan for the total destruction of *unflayed* carcases. Cremation would, of course, be the ideal method to be adopted, but the expense of burning a large number of carcases during the spring months would be considerable, and could only be met by the co-operation of a number of sheep-owners. If small kilns or destructors could be erected in suitable situations, arrangements might be made for working them more economically than would be possible for the individual owner. Failing cremation, the carcases should be buried deeply in the ground where practicable; when the character of the soil prevents any but shallow graves being dug, then plots of ground should be fenced off and used only for burial purposes, as suggested by Dr Hamilton for cases of "braxy."

[1] *Annual Report of the Bureau of Animal Industry, U.S.A., for* 1898.

It is certain that the total destruction of unflayed carcases would ultimately bring about a gradual decrease in the number of cases.

Second, an attempt was next made to show whether protective inoculation against "black-quarter" in sheep was of any value. As is well known, considerable success has attended the adoption of protective inoculation of young cattle against "black-quarter," both in this country and abroad. Mr Gilruth, M.R.C.V.S, the chief veterinarian and bacteriologist to the New Zealand Government, recently reported that in one district alone 2250 calves have been vaccinated as a preventive measure, with a subsequent loss of only two animals. He also mentions that in a district where "black-quarter" is very rife, "if done twice a year vaccination is a great success[1]."

I hoped to find that protective inoculation of sheep would prove equally valuable. Unfortunately, I was unable to obtain any vaccines especially prepared for sheep, and I was obliged to try those used for cattle. These vaccines were of the usual type—virulent muscle, dried and attenuated by heat, and then reduced to a powder.

During 1903 I used three vaccines:

A. A double vaccine (English).

B. A single vaccine (foreign).

C. The first dose of the double vaccine *A* used as a single vaccine.

As will be shown later, none of these vaccines proved quite satisfactory, and, as they were kindly given to me for trial, I have not made known their origin.

In the spring of 1903 I vaccinated a small number of sheep at the College Farm with the vaccines *A* and *B*, chiefly with the object of finding which was the most suitable part of the body for the purpose. In some the interdigital space of a forefoot was selected as the seat of the inoculation, in others the inside of the thigh or the axilla. In all cases the skin was first scrubbed with a 2 per cent. solution of lysol.

When the double vaccine was used the first dose was given in a right limb, the second eight days later in a left limb. None of the sheep suffered any inconvenience from the injections, whether given in the feet, or under the skin of the thigh or of the axilla. As the inside of the thigh was found to be the most convenient situation for the injection, it was generally selected in the later experiments.

[1] *Report of the Division of Veterinary Science of the New Zealand Department of Agriculture*, 1904.

From this lot of vaccinated sheep I then selected two, one twice vaccinated with *A*, the other vaccinated with *B*. A third sheep, which was unvaccinated, was used as a control animal. All three were inoculated with virulent "black-quarter" muscle injected deeply into the muscles of the thigh, each animal receiving exactly the same dose. Within 24 hours the unvaccinated sheep and one of the vaccinated (single *B*) sheep were dead, while the third sheep, which had been twice vaccinated (double vaccine *A*) remained unaffected by the dose of virulent muscle it had received. The two sheep which died presented the usual appearance of badly "struck" sheep. The doubly vaccinated sheep was lame for some days owing to the pain caused by the puncture, but no symptoms of "black-quarter" were developed.

From this result I concluded that the double vaccine would prove most efficient in giving immunity against the naturally acquired disease.

In the summer of 1903 I arranged with a number of sheep-owners to vaccinate small lots of sheep in various parts of Romney Marsh during the following winter.

As I fully anticipated the possibility of some slight loss resulting from the inoculations, it was arranged that compensation should be paid for any sheep which died from the action of the vaccine.

Judging from the risks met with in the vaccination of cattle I had no reason to expect that the loss in sheep would be more than 1 or 2 per cent., but of the 308 sheep vaccinated during October, November, and December, 14 died within a few days, and the deaths were evidently due to the vaccination, making a loss equal to $4\frac{1}{2}$ per cent.

Of the 14 deaths only one was due to the foreign vaccine *B*; the remaining 13 deaths were caused by the English vaccines *A* and *C*.

Table I shows the loss caused by each of the three vaccines:

An examination of this table shows that:

1. The foreign vaccine *B* was used on 218 sheep with the loss of one only, or less than $\frac{1}{2}$ per cent. Vaccine *B* may therefore be regarded as practically free from risk when used on sheep.

2. The double vaccine *A* caused a loss of 11 sheep out of 80 vaccinated, or nearly 14 per cent Of the 11 deaths, one was caused by the first dose, 10 by the second. The deaths were directly due to the vaccination, occurring about 48 hours after the operation. The lesions of "black-quarter" were well marked, and were localized at the seat of the inoculation.

3. The single vaccine *C* was only tried on 10 sheep with a loss of two, or equal to 20 per cent.

The loss of 11 sheep caused by the double vaccine *A* was most

unfortunate, as it compelled me to abandon its use, although I had already shown that a high degree of immunity was to be expected when it was tried on an extensive scale. It is of course possible that had a large number of sheep been vaccinated with *A* the percentage of loss would have been greatly reduced, but I was not in a position to risk any further loss, and was obliged to be satisfied with the small number of sheep (69) which had passed safely through the inoculations.

TABLE I.

DEATHS DUE TO VACCINATION.

Owner	No of Sheep Vaccinated	Deaths due to Vaccination
	THE DOUBLE VACCINE (A)	
Mr E Lord	30	1 (2nd dose)
Mr A Finn	50	10 (1 due to 1st dose, 9 due to 2nd dose)
Total	80	11 total loss (nearly 14 per cent)
	THE SINGLE VACCINE (B)	
Mr E. Lord	40	0
Mr A. Finn	40	0
Mr L J Pankhurst	20	0
Mr T. J Pearson	49	0
Mr Geo Neve	69	1
Total	218	1 total loss (less than ½ per cent.)
	THE SINGLE VACCINE (C)	
Mr T J. Pearson	10	2 (loss 20 per cent.)

This vaccine had been used on a small number of sheep with perfect safety at the College Farm in the spring, but when used in October in Romney Marsh the result was disastrous, 11 sheep out of 80 being killed by it. In the spring the sheep used in the experiment were well protected from bad weather during the critical period following the inoculations. In October the sheep used in the experiment were living in the open, and were exposed to adverse climatic conditions.

It seems possible that exposure to bad weather during the 48 hours following the inoculations may be a cause of loss. Anything which would lower the vitality of the sheep might give the organisms contained

in the vaccine the upper hand, and allow them to produce the actual disease instead of merely rendering the animals immune. This theory is supported to some extent by what occurred in connection with the loss of nine sheep due to the second dose of vaccine *A*.

Two lots of sheep in different parts of Romney Marsh were given the second dose of vaccine *A* on the same day, the same dose being used for all the sheep.

In one lot not a single sheep suffered any inconvenience, in the other nine sheep died from the inoculations during the next three days.

For the 48 hours following the inoculation of the two batches of sheep the weather was most unfavourable, for a strong south-westerly gale was blowing, with heavy rainstorms. The sheep in which the loss occurred were near the coast, and were absolutely without shelter, exposed to the full force of the gale. The other lot, in which no deaths occurred, were several miles further inland and in a much less exposed situation, some shelter being provided by trees, hedges, buildings, &c.

Later, the first dose of the double vaccine *A* was tried on 10 sheep as the single vaccine *C*, but in a reduced dose. Two out of the 10 sheep died within 48 hours. On enquiry it was found that the weather had again proved unfortunate during the critical period, the nights being very cold with sharp frost[1]. It should be mentioned that before this loss occurred altogether 90 sheep had been given the first dose of vaccine *A* with the loss of one sheep only, yet a reduced dose used in cold weather caused the loss of two out of 10 sheep.

The sheep which had passed safely through the vaccination, together with a number of unvaccinated sheep, were pastured on land well known to be dangerous. The whole of the sheep, about 550 in number, were kept on the dangerous pastures until June, 1904, and careful records were kept of the number of "struck" sheep in the two classes.

From these records the following tables were prepared, showing the number of sheep which were "struck" up to the conclusion of the experiment. It was impossible for me to examine all the sheep which were "struck," but from time to time samples of diseased muscle were sent to me for examination, and in these I was able to detect the presence of the "black-quarter" bacillus.

In the tables below the losses in "struck" sheep in vaccinated and unvaccinated animals have been compared by reducing the figures to a percentage, but of course with such small numbers percentages are

[1] It is interesting to note that sheep owners insist that more sheep are "struck" on frosty nights in spring than at any other time.

not altogether satisfactory Very different results might be obtained even with the same vaccines if used on a much greater number of animals.

TABLE II

The Double Vaccine *A*.

Time of Vaccination	Owner	No of sheep vaccinated	No of sheep "struck"	Percentage of loss in vaccinated sheep	No of unvaccinated sheep	No of sheep "struck"	Percentage of loss in unvaccinated sheep
October, 1903	Mr E Lord, jun	29	0	0	111	2	1 80
October, 1903	Mr A Finn	40	1	2½	50	9	18
		69	1	1 44	161	11	6 83

TABLE III

The Single Vaccine *B*.

Time of Vaccination	Owner	No of sheep vaccinated	No of sheep "struck"	Percentage of loss in vaccinated sheep	No of unvaccinated sheep	No of sheep "struck"	Percentage of loss in unvaccinated sheep
October, 1903	Mr Lord	40	0	0	111	2	1 8
October, 1903	Mr Finn	40	8	20	10	1	10
November, 1903	Mr T J Pearson	49	2	4	51	2	4
November, 1903	Mr Pankhurst	20	1	5	20	2	10
December, 1903	Mr Neve	68	3	4 4	65	6	9 2
		217	14	6 45	257	13	5 05

TABLE IV

The Single Vaccine *C*.

Time of Vaccination	Owner	No of sheep vaccinated	No of sheep "struck"	Percentage of loss in vaccinated sheep	No of unvaccinated sheep	No of sheep "struck"	Percentage of loss in unvaccinated sheep
November, 1903	Mr Pearson	8	1	12½	51	2	4

These tables show very clearly the success or non-success of the vaccines in securing immunity.

TABLE II.

Of the 69 vaccinated sheep only one was "struck," equal to a loss of 1·44 per cent., while of the 161 unvaccinated sheep 11 were "struck," equal to a loss of 6·83 per cent.

But the most remarkable result was obtained in the sheep owned by Mr A. Finn, of Lydd. These sheep, 90 in number, were kept from October, 1903, to June, 1904, on a particularly dangerous pasture at Broomhill.

Mr Finn states that during his occupation of this land he has had 16 to 20 per cent. of sheep "struck" annually.

Out of the 40 vaccinated sheep only one was "struck," or a loss of 2½ per cent., while of the 50 unvaccinated sheep nine were "struck," making a loss of 18 per cent.

It has already been shown that a high degree of immunity can be produced in sheep by the use of this double vaccine—a vaccinated sheep has resisted the introduction of a known quantity of highly virulent material which was capable of killing two control animals in 24 hours. It seems therefore reasonable to assume that the remarkable contrast between the number of sheep "struck" in the vaccinated and unvaccinated animals is due to the effect of the double vaccine *A* which rendered the 40 sheep strongly immune against "black-quarter" and consequently only one was "struck."

It is possible that the suggestion may be made that this result was due to the fact that all susceptible animals were killed off by the doses of vaccine and that the remaining sheep were naturally immune against the disease. Such an objection might equally be made where cattle are vaccinated against "black-quarter" or where cattle and sheep are vaccinated against "anthrax," and it would be difficult to refute the suggestion except by the comparison of losses in very large numbers of vaccinated and unvaccinated animals.

TABLE III.

Of the 217 vaccinated sheep 14 were "struck," a loss equal to 6·45 per cent., while of the 257 unvaccinated sheep 13 were "struck," or a loss equal to 5·05 per cent.

The single vaccine *B* has failed to protect sheep against "black-quarter," but it is possible that different results might be obtained if this vaccine were used nearer to the dangerous spring season. An examination of the table shows that Mr Neve's sheep, vaccinated at the end of December, 1903, seem to have had a slight degree of immunity. Of the 68 vaccinated sheep three were "struck," equal to a loss of 4·4 per cent., while of the 65 unvaccinated sheep six were "struck," making a loss equal to 9·2 per cent. The annual loss on this land was said to be 9 per cent.

TABLE IV.

The single vaccine *C* caused the loss of two sheep out of 10, and its use was abandoned. Of the eight sheep remaining one was afterwards "struck," so that this vaccine was powerful enough to kill and yet failed to give a strong immunity.

The conclusions which may be drawn from these attempts to immunise sheep against "black-quarter" are:

1. That the double vaccine *A* undoubtedly renders sheep strongly immune against "black-quarter."

2. That the double vaccine *A* is uncertain in its action, and under certain conditions may be highly dangerous when used in the field

3. That a single vaccine may be powerful enough to kill and may yet fail to give a lasting immunity to those animals which survive the inoculations.

4. That none of the vaccines tried in these experiments have proved entirely satisfactory, although enough has been done to show that the loss from "struck" sheep could be greatly diminished by protective inoculation, if a safe and efficient vaccine were available.

It is possible that more favourable results will be obtained in the future by the use of vaccines specially prepared for sheep. Experiments are now being conducted on these lines and the results will be communicated on their completion.

ON THE ACCUMULATION OF FERTILITY BY LAND ALLOWED TO RUN WILD.

By A. D. HALL,

Director of the Rothamsted Experimental Station (Lawes Agricultural Trust).

It is well known that the fertility of "virgin" soils is due to the accumulation of the *débris* of a natural vegetation which has been in occupation of the soil for a long epoch previously. Only when the climate and rainfall are suitable to the growth of the plants and the partial preservation of their residues does a virgin soil of any richness arise; on the one hand, virgin soil may be as poverty stricken as the most worn-out European field because it has never carried any vegetation; on the other hand, as in the tropics, the *débris* of an extensive vegetation may decay with such rapidity that no reserve of fertility accumulates. In temperate climates, and with a particular distribution of the annual rainfall, occur the grassy treeless prairies and steppes which provide the ideal conditions for the accumulation of fertility. But that fertility does increase when land is in the state of permanent grass has long been an axiom in our farming; the results set out below will serve to show at what rate the increase takes place under prairie conditions in this country, *i.e.* when the land is left absolutely to itself and not even grazed by stock.

In 1882 about an acre of the upper end of the Broadbalk field at Rothamsted, which had then been carrying wheat for forty years in succession, was not harvested, the crop was allowed to stand and shed its seed without cultivation of any kind. In the following season a fair quantity of wheat came up on this part of the field, but gradually got weaker as the season advanced and the weeds increased their hold on the land. The wheat was still left to struggle on without cultivation, and by the fourth season only three or four stunted plants

could be found, each carrying but one or two grains in the ear. With these the wheat disappeared and has never been seen again in that part of the field. This illustrates the fact that our farm crops have become so specialised that they are unable to exist in competition with weeds and other natural vegetation, and are entirely dependent on cultivation to relieve them from that competition. The piece of land in question has been left untouched since that time, and has covered itself with a coarse grassy herbage interspersed with thorn bushes and briars, young oaks, and other shrubs of the district. Before, however, these shrubs could meet and establish a continuous covert they were stubbed from one portion so as to leave the herbaceous and grassy vegetation only in possession. This piece of land now represents the result of something more than 20 years of prairie conditions in England, and as samples of soil had been taken at starting it affords an opportunity of gauging the rate at which fertility is accumulating. A very similar experiment was also made with a portion of the Geescroft field, which had carried beans from 1847 to 1878 and clover from 1883 to 1885; after the second cutting of clover in 1885 the field was fenced off and has been left untouched ever since.

The fate of these two pieces of waste land was a matter of great interest to the late Sir John Lawes, he constantly referred to them, and in 1895 wrote a suggestive little paper on them and on the vegetation they then carried in the *Agricultural Students' Gazette* (R. Ag. Coll. Cirencester, 1895, p. 65). In this paper Sir John Lawes discussed the probable character of the Rothamsted soil when it was in its "virgin" condition, and the exhaustion it may be supposed to have suffered during its many centuries under arable cultivation.

Table I shows the carbon and nitrogen in the soil at the beginning of the experiment and in 1904. Both fields show a marked gain of carbon and nitrogen down to the third depth of 27 inches, the increase in the lower depths being due to the roots which have decayed in that stratum. It is difficult to convert these percentages into actual quantities per acre, owing to the uncertainty which must exist as to the layer of soil which is under examination. The sampling tool is driven down each time to the depth of nine inches, but the evidence points to a much more consolidated state of the soil in 1882, when it had been under arable cultivation with artificial manures alone for forty years, than in 1904 when it had long been in grass. Consequently the successive layers taken by the tool in 1904 are lighter than they were in 1882, they are essentially a little thinner

since the soil has been, as it were, expanded in the interval by the accumulation of organic matter. But because the organic matter decreases as one gets lower in the soil, the thinner slices of the later samples exaggerate the percentage of organic matter in the soil. It is almost impossible to introduce a correction except by taking such a large number of soil samples that the error in calculating from a sample six inches square the weight of soil per acre is

TABLE I.

Accumulation of Carbon and Nitrogen in Soil of Land allowed to run wild for more than 20 years.

	Per cent. in Dry Soil			
	Carbon		Nitrogen	
	1881-3*	1904	1881-3*	1904
Broadbalk, 1st 9 inches	1·143	1·233	0 1082	0·1450
,, 2nd 9 ,,	0·624	0 703	0·0701	0 0955
,, 3rd 9 ,,	0 461	0 551	0·0581	0 0839
Geescroft, 1st 9 inches	1 111	1·494	0·1081	0 1310
,, 2nd 9 ,,	0·600	0 627	0 0739	0·0829
,, 3rd 9 ,,	0 447	0 438	0·0597	0·0652

* Broadbalk, 1881; Geescroft, 1883.

eliminated. If the total amounts of nitrogen in the Broadbalk soils be calculated on the assumption that the weights of the soil layers were the same in 1904 as in 1882, the total gain of nitrogen per acre would amount to 2200 lbs., which is at the rate of more than 100 lbs. per acre per annum So great an accumulation of nitrogen is manifestly impossible to account for in the present state of our knowledge, and as the introduction of any allowance for the lightening of the soil would be a very speculative proceeding, it is better to let the results stand for the present as only comparable with the similar results obtained on the Geescroft field. The Geescroft field shows

a similar though smaller increase in the proportion of carbon and nitrogen down to the depth of 27 inches; considering the surface soil only the difference in the amount of nitrogen accumulated by the two fields amounts to about 350 lbs. per acre. The fact that the increase on Geescroft is smaller than on Broadbalk is of considerable interest, because after the Geescroft sample had been taken in 1883 clover was grown for three years before the land was allowed to run wild. Moreover the soil was sampled again in 1885, after three years' growth of clover, and showed in the surface soil an increase of nitrogen, which then amounted to 0·1152 °/$_{o}$ instead of 0·1081 °/$_{o}$ in 1883. The Geescroft field had in fact some start of the Broadbalk field, why did it not maintain its lead? The answer is probably to be found in the botanical composition of the wild herbage which has taken possession of these two bits of waste.

It should be remembered that previously the Broadbalk land had been growing wheat, the Geescroft field beans until they would grow no longer, then a good crop of clover. At the present time the vegetation on the Broadbalk waste contains a fair proportion of leguminous plants, chiefly meadow vetchling, while this class of plants is and has been for many years, since the dying out of the clover, absent from the Geescroft waste. It is impossible to refrain from correlating the absence of leguminous herbage on these old bean and clover plots with the well-known fact that land becomes "sick" of the leguminous crops in a way that never happens with the other farm crops. As Sir John Lawes pointed out in the paper already referred to, the Black Medick is a persistent weed in the Rotation field on the plots which are bare fallowed, but not on the plots which grow clover or beans once every four years. Further, the absence of leguminous herbage collecting nitrogen from the atmosphere would explain why the Geescroft field has gained nitrogen less rapidly than has the Broadbalk field with its more mixed herbage.

Another question however arises; how comes it that the Geescroft land, with no plants growing on it which are capable of fixing free nitrogen, has yet gained an enormous quantity of nitrogen during the twenty years under review, a quantity which at the lowest reckoning amounts to about 25 lbs. per acre per year? The nitrogen brought down in the rain would account for perhaps 5 lbs. per acre per annum, a little more will come in the form of dust, bird-droppings, and other casual increments, while some may be due to fixation of atmospheric nitrogen by bacteria in the soil not associated with leguminous plants,

like the *Azotobacter chroococcum* of Beyerinck and Winogradsky's *Clostridium Pastorianum*. The *Azotobacter* has been found abundantly in the Rothamsted soils, and as in the case of grass land like the present the decaying vegetation would supply the carbohydrate which the bacterium must oxidise in order to fix nitrogen, it is quite possible that it may have effected considerable gains of nitrogen. Two other causes may be at work, the absorption of atmospheric ammonia by soil and plant, and the rise of nitrates from the subsoil. To what extent the traces of ammonia in the atmosphere are absorbed by the soil, as distinct from the washing down of ammonia by the rain, is still a matter of uncertainty, the investigations of Kellner and of Schloesing indicate a comparatively high figure, about 40 lbs. per acre per annum as a maximum. But a gain of nitrogen from this source should be even more in evidence on the arable than on grass land, yet the unmanured plots on the arable land do not show any similar amounts of nitrogen either in soil or in crop. Again, though practically no nitrates are found in the drainage water immediately below grass land, both because nitrification is slow and the living plant is active in taking up the nitrates as fast as they are formed, yet nitrates are comparatively abundant in the permanent subsoil water. No data exist on the subject, but it is not unreasonable to suppose a certain amount of capillary creep of these nitrates up to the zone where the surface vegetation could reach them. Only by the capillary movements of subsoil nitrates, laterally or vertically, can one understand how trees in many places continue to obtain the requisite nitrogen for their yearly increase. However, from one cause or other, this Geescroft field during its twenty years of lying in rough natural vegetation does show an increase in fertility which is not entirely easy to account for on ordinary lines.

The contrast between the vegetation of the two plots is very considerable, and as a complete botanical separation was made of portions cut in 1903, the amounts contributed by the chief species are set out in Table II.

It will be seen that not only is the Geescroft herbage practically without leguminous plants, but it consists almost wholly of a single grass, *Aira cæspitosa*, which occurs to but an inappreciable extent on Broadbalk, where the herbage is of a much more general nature.

It is difficult to account for the extraordinary differences in the herbage of these two pieces of land; the two fields are not far apart, and, as the mechanical analyses given in Table III show, the soils are of very similar physical structure.

TABLE II.

Composition of Herbage on Land that has run wild for more than 20 years. June, 1903.

		Broadbalk	Geescroft	
GRAMINEOUS HERBAGE				
	Number of Species	11	10	
	Botanical Names :—	Per cent.	Per cent.	
Gramineæ	1. Phleum pratense.................	4·89	0·08	Catstail
Gramineæ	2. Agrostis alba	11·02	0·20	Common Bent
Gramineæ	3. Aira cæspitosa.................. ..	—	86·19	Tufted Hair-grass
Gramineæ	4. Arrhenatherum avenaceum ..	3·50	2·34	False Oat-grass
Gramineæ	5. Dactylis glomerata..............	35·12	4·53	Cocksfoot
Gramineæ	6. Lolium perenne	3·22	0·05	Perennial Rye-grass
	Other species amounting to...	1·89	1·87	
	Total...	59·64	95·26	
LEGUMINOUS HERBAGE				
	Number of Species	5	2	
Leguminosæ	1. Trifolium repens . ..	3·08	0·05	White or Dutch Clover
Leguminosæ	2. Trifolium pratense ..	0·55	—	Common Red Clover
Leguminosæ	3. Vicia sepium	0·40	0·38	Bush Vetch
Leguminosæ	4. Medicago lupulina .	2·92	—	Black Medick
Leguminosæ	5. Lathyrus pratensis ...	18·36	—	Meadow Vetchling
	Total ..	25·31	0·43	
MISCELLANEOUS HERBAGE				
	Number of Species	24	14	
Umbelliferæ	1. Heracleum sphondylium	4·28	1·71	Cow Parsnip or Hogweed
Dipsaceæ	2. Scabiosa arvensis.......	2·87	—	Field Scabious
Compositæ	3. Centaurea nigra	1·05	—	Black Knapweed
Compositæ	4. Carduus arvensis	0·81	0·30	Creeping Plume Thistle
Plantagineæ	5. Plantago lanceolata	2·46	0·26	Ribwort Plantain
Polygonaceæ	6. Rumex obtusifolius	—	0·94	Broad-leaved Dock
	Other species amounting to...	3·58	1·10	
	Total...	15·05	4·31	
SUMMARY				
	Gramineæ	59·64	95·26	
	Leguminosæ	25·31	0·43	
	Miscellaneous species ...	15·05	4·31	
	Total ..	100·00	100·00	

TABLE III.

Mechanical Analysis of Soil with wild Vegetation.
Rothamsted, 1904.

Percentages dried at 100° C.

	Soil to 9″		Subsoil 10—18″	
	Broadbalk	Geescroft	Broadbalk	Geescroft
Fine Gravel, 3 to 1 mm.	1·88	2·05	1·14	2·33
Grit, 1 to 2 mm.	6·15	5·13	3·16	3·19
1st Sediment, 0·2 to 0·04 mm.	22·95	27·88	11·86	17·69
2nd Sediment, 0·04 to 0·01 mm.	25·32	25·65	14·63	24·83
3rd Sediment, 0·001 to 0·004 mm.	7·98	7·17	5·56	7·14
4th Sediment, 0 004 to 0·002 mm.	4·02	4·09	4·14	3·85
Klay, below 0·002 mm.	21·17	23·49	50·88	29·55
Loss on solution and moisture	9·0	3·87	8·46	5·85
Total...	98·47	99·33	99·83	94·43

Despite the identity of the mechanical composition of the two soils, the Geescroft field when under arable cultivation had always the reputation of being the wettest and most unworkable field on the farm. During the earlier years of the Rothamsted experiments both oats and beans were grown upon this field, yet it was found impossible to continue the trials, so frequent were the failures to obtain a plant through the intractable nature of the ground in a wet season. Where nitrate of soda was used the land became specially difficult to manage, remaining persistently wet and then drying with an excessively hard crust. For example, we read that in 1877 the land could not be worked in time for sowing oats; the last crop was in 1878, "since which, owing to the wetness and foulness of the land for several years, it was left fallow." On the same field again, during the eleven years, 1871–81, it was only possible to obtain four crops of beans, so wet was the land. Even at the present time water may often be seen standing on this field, although it is practically at the highest part of the farm, and there is nothing in its surroundings to lead surface water towards it. It is true that it is not underdrained as the Broadbalk field is, but on none of the Rothamsted land would tile drainage be usually considered necessary, for the soil is lighter than a true clay

and the porous chalk lies only a few feet below. The mechanical analysis indeed indicates a lighter subsoil for Geescroft than for Broadbalk, and this is borne out by the existence of pits, from which sand is won, not very far from the Geescroft field. The vital difference to be found in the soil of the two fields is the presence of chalk in the surface soil of Broadbalk and its absence in the Geescroft soil. The soil of the Rothamsted estate contains naturally no carbonate of lime, but during the eighteenth century most of the arable fields were heavily chalked by the simple process of sinking a pit through the clay to the chalk rock below, which was then drawn out and spread on the land. Thanks to this the Broadbalk field contains to-day about 3 per cent of chalk in its surface soil, though little or none is present in the lower layers; the Hoos field contains about 2 per cent., Barnfield about the same, while some parts of Agdell field contain as much as 5 per cent. Now the Geescroft field contains about the same proportion as is to be found in the natural uncultivated soil from the adjoining Harpenden Common, a little more than one-tenth per cent of carbonate of lime, so that evidently it must have escaped the chalking processes, which were already dying out when Sir John Lawes came into possession in 1835. Table IV shows the amount of Calcium Carbonate in the first and second nine inches of the soils of these two fields and

TABLE IV.

Calcium Carbonate in Rothamsted Soils, 1904

Percentages in Soil dried at 100°.

	Broadbalk	Geescroft	Harpenden Common
1st depth 0—9″	3 325	0 160	0 210
2nd depth 10—18″	0·126	0·131	0 136

of the uncultivated Harpenden Common. It is impossible to resist the conclusion that the unworkability of Geescroft, which practically caused its abandonment as an experimental field and indeed as arable land at all, and the extraordinary differences to be seen in the natural herbage it now carries, are due to the lack of the chalking received by the other Rothamsted fields. The previous cropping may have caused the absence of leguminous plants from the Geescroft herbage, but the

difference in the grass flora, the predominance of *Aira* instead of *Dactylis*, must be due to the wetter character of the Geescroft land, and this appears to be brought about, neither by differences in the physical constitution of the soil nor by lack of drainage, but simply by the absence of carbonate of lime to coagulate the clay particles and make the mass permeable to air and water.

In any case the great contrast between the vegetation on these two pieces of land—identical in character and situation, not half-a-mile apart, on the same level—shew what large effects, both on the natural herbage and on the suitability of the soil for particular crops, can be brought about by small variations in some of the numerous factors controlling the condition of the soil and the nutrition of the plant.

THE INHERITANCE OF STERILITY IN THE BARLEYS.

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THE following note is concerned solely with the behaviour of certain characters in hybrid barleys which bear on the inheritance of sterility and the question whether sex is, as it seems possible, a phenomenon of gametic segregation[1]. I have used the term "sterility" in a broader sense than usual to include cases in which certain florets set no grain owing to the suppression of either the female or both the male and female reproductive organs. The plants themselves are in no cases completely sterile. The other characters occurring in the numerous varieties of barley will be considered in detail later.

At present our knowledge of the subject is naturally a meagre one, for the precise study of the phenomena of inheritance is too recent for much material to have accumulated. There is, it is true, a great deal of literature dealing with the sterility of hybrids, but it is concerned with problems which for the moment we may neglect, such as whether the existence of sterility in a hybrid was a criterion of its parents being distinct species or not. Very little of it has any bearing on its inheritance.

The more important exceptions are the crosses made by Rimpau[2] and others between "six-row" and "two-row" barleys, from which it is clear that the fully fertile "six-row" type behaves as a recessive. This has been confirmed by Tschermak[3], who has also shown that, on

[1] Since writing the above Mendel's correspondence with Nageli has been published by Correns in the *Abhandl. d. K.S. Gesellsch. d. Wissensch., math.-phys. Kl.* XXIX. III. p. 241 from which it appears that Mendel himself was aware of this possibility.

[2] Rimpau, *Landw. Jahrb.* Bd. XX. p. 335, 1891.

[3] Tschermak, *Zeits. Landw. Versuchs. Oesterreich*, 1901, Heft II. p. 1029.

segregation occurring in the first generation from the hybrids, three "two-row" types are produced to each "six-row." Up to the present time no one seems to have called attention to the bearing of this fact on the inheritance of sterility. More recently Bateson[1] has investigated an interesting case occurring among certain sweet pea hybrids in which sterility, due to abortion of the anthers, behaves as a recessive character.

The following short account of the morphology of the inflorescences of the chief sub-species into which our cultivated barleys have been grouped will show how suitable they are for such studies.

The distinguishing characteristic of the genus Hordeum is that the single-flowered spikelets are arranged in groups of three, which alternate with one another on opposite sides of the rachis. The flowers themselves are typically hermaphrodite, as in the majority of the Gramineae. In certain sub-species of *H. sativum* the two lateral florets of the groups are staminate only and the median one hermaphrodite, whilst in another sub-species the reduction of the lateral florets is carried to a still greater extent, and, owing to the suppression of both the stamens and ovaries, the florets become sexless. In extreme cases they may be represented by the outer glumes only. The opposite type of reduction, with the stamens disappearing first, leaving a female flower, is unknown.

The first group is represented by the sub-species *H. hexastichum* and its varieties, the "six-row" barleys, and also the so-called "four-row" barleys. These latter have been grouped by Koernicke under the name of *H. tetrastichum*[2], and they are popularly supposed to have become four-rowed by the suppression of the median floret. Such, however, is not the case, for all the florets are fully developed, and the ears owe their square appearance solely to the length of the internodes and the angle at which the florets are set. Beaven more appropriately names the group *H. vulgare*[3].

Closely related to these two sub-species is the little-known group *H. intermedium*[4], containing at present only two varieties, characterised by the fact that the lateral florets, though perfect, are considerably smaller than the median ones. This forms a link between the six-row and the two-row barleys composing the sub-species *H. distichum* and *H. nutans*, which are represented more or less accurately in this country by the Chevalier and Goldthorpe varieties. In these varieties

[1] Bateson, Presidential Address, Sect. D, British Assoc. Meeting, 1904.

[2] Koernicke and Werner, *Handbuch des Getreidebaues*, p. 147.

[3] Beaven, *Journ. Fed. Inst. of Brewing*, Vol. VIII. No. 5, p. 542.

[4] *Ibid.*

the lateral florets are staminate only. It is extremely rare to find ears in which any of the laterals are hermaphrodite. I have, however, met with such cases in an unnamed variety of hybrid origin in which here and there a lateral floret gave rise to a small grain.

The extreme case in which the lateral florets are sexless or even almost completely suppressed is represented in the sub-species *H. decipiens*, a number of varieties of which are cultivated in Abyssinia. For the sake of convenience I have called this the "Abyssinian" type in the following account.

Varieties of all these sub-species have been crossed together, some in 1900, others in 1902 and 1903, and the results of combining each of these types in every possible way can now be traced. In all cases the hermaphrodite median florets only were used as parents.

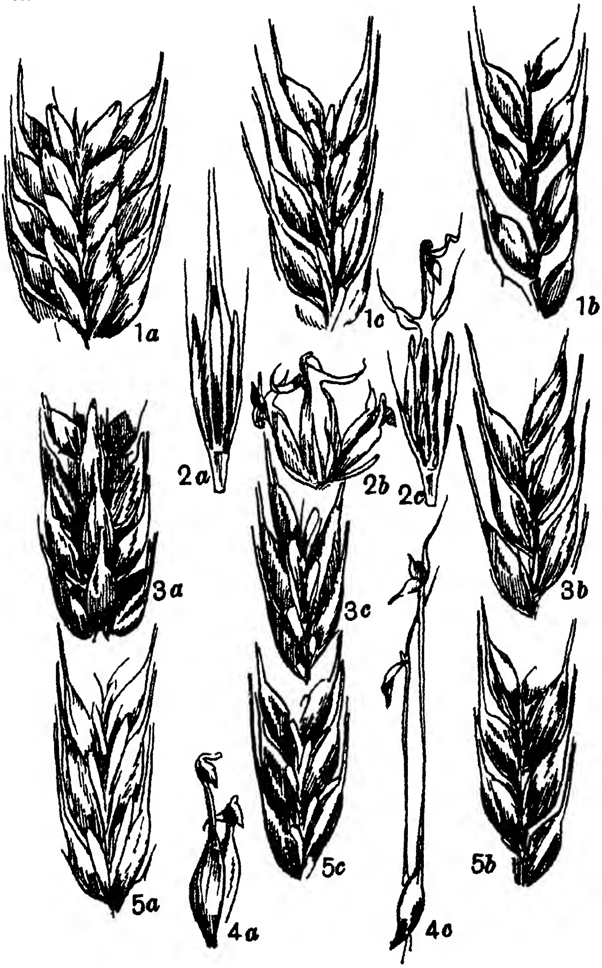
The varieties experimented with are as follows:

Six-row	*H. hexastichum*	*H. japonicum*
		H. Schimperianum
		H. pyramidatum
		H. hexasticofurcatum
		H. eurylepis
	H. vulgare	*H. violaceum*
		H. vulgare
		H. trifurcatum.
	H. intermedium	*H. transiens.*
Two-row	*H. distichum*	*H. zeocriton*
		H. inerme
		H. nigrosubinerme
	H. nutans	*H. nutans*
	H. decipiens	*H. deficiens*
		H. Steudelii
		H. Abyssinicum.

In addition to these I have also hybridized *H. spontaneum*, a two-rowed type supposed to be the species from which our cultivated barleys have originated. Detailed descriptions of all of these varieties will be found in Koernicke and Werner's *Handbuch des Getreidebaues.* The degree of sterility in the hybrid plants (F_1) was as follows:

H. hexastichum × *H. intermedium* (six-row × six-row with smaller lateral florets); hybrid with well-developed median but smaller lateral florets.

H. Schimperianum × *H. nutans* (six-row × two-row); hybrid with staminate lateral and fertile median florets



H. hexastichum × *H. nutans* (six-row × two-row); hybrid with staminate lateral and fertile median florets.

H. transiens (Fig. 1*a*) × *deficiens* (Fig. 1*b*) (six-row with small lateral florets × Abyssinian type); hybrid with fertile median florets and sexless laterals (Fig. 1*c*).

H. spontaneum × *H. eurylepis* (two-row × six-row); hybrid with fertile median and sterile lateral florets.

H. spontaneum (Fig. 2 *a*) × *H. hexasticofurcatum* (Fig. 2 *b*) (two-row × six-row); hybrid similar in the degree of its sterility to the preceding (Fig. 2 *c*).

H. nigrosubinerme × *hexasticofurcatum* (two-row × six-row); hybrid with fertile median and sterile lateral florets.

H. pyramidatum × *H. deficiens* (six-row × Abyssinian type); hybrid with fertile median florets, but sexless lateral florets.

H. deficiens × *H. pyramidatum*, the reciprocal cross of the above, gave the same result.

H. deficiens × *H. japonicum* (Abyssinian type × six-row); hybrid of the Abyssinian type.

H. japonicum × *H. Steudelii* (six-row × Abyssinian type); hybrid of the Abyssinian type.

H. vulgare (Fig. 3 *a*) × *H. Steudelii* (Fig. 3 *b*) (six-row × Abyssinian type); hybrid of the Abyssinian type (Fig. 3 *c*).

H. Abyssinicum × *H. trifurcatum* (Fig. 4 *a*) (Abyssinian type × six-row); hybrid of the Abyssinian type (Fig. 4 *c*).

H. deficiens × *H. violaceum* (Abyssinian type × six-row); hybrid of the Abyssinian type.

H. inerme × *H. transiens* (two-row × median florets large, lateral reduced in size but fertile); hybrid median florets fertile, lateral staminate only.

H. trifurcatum × *H. nutans* (six-row × two-row); hybrid with fertile median and staminate lateral florets.

H. zeocriton × *H nutans* (two-row × two-row), hybrid, similar to the parents with regard to the presence of sterile florets.

H. nutans (Fig. 5 *a*) × *H. Steudelii* (Fig. 5 *b*) (two-row × Abyssinian type); hybrid of the Abyssinian type (Fig. 5 *c*).

H. deficiens × *H. nutans* (Abyssinian × two-row); hybrid of the Abyssinian type.

H. Abyssinicum × *H. Steudelii* (Abyssinian × Abyssinian type); hybrid of the Abyssinian type.

The cross-bred six- and two-row barleys gave two-row barleys with staminate lateral florets similar to those of the two-row parents, but the cross-breds with the Abyssinian types as one parent and two- or six-row barleys as the other, produced lateral florets which were larger than those of the Abyssinian parent. On dissection each floret was found to consist of two feebly developed paleae, but no sexual organs were

present. It is therefore evident that the six-row type is recessive to the intermedium, two-row, and Abyssinian types, the intermedium to the two-row, and the two-row to the Abyssinian without exception. In other words, the types with completely sterile lateral florets are dominant over those with either male or hermaphrodite laterals, and the types with male lateral florets are dominant over those with hermaphrodite florets, whether fully developed or reduced in size.

The first generation from these cross-breds has still to be raised in the majority of the cases described. Where it has been grown the segregation has been of the normal type, resulting in the ratio of three of the dominant to one of the recessive forms.

Thus, for instance, *H. hexastichum* × *H. nutans* in this generation gave 193 two-rowed to 62 six-rowed, and *H. nutans* × *H. Steudelii* 85 of the Abyssinian type to 30 of the two-row type. In addition to these a hybrid of unknown descent gave 208 two-rowed and 66 six-rowed individuals

In these cases, then, the various degrees of sterility, ranging from complete suppression of the reproductive organs in the lateral florets to reduction in size only, are clearly dominant over the perfectly developed floret.

We have now to consider cases in which certain of these types have been crossed with others bearing additional florets.

Many varieties of barley produce supernumerary florets on the paleae. These are the "kaputzen" of the German, or the "trifurcate paleae" of English systematists. They occur originally in *Hordeum trifurcatum* (Fig. 4 *a*), a barley cultivated in the Himalayas and frequently known under the name of Nepaul barley, or even Nepaul wheat[1]. The numerous varieties with trifurcate paleae described by Koernicke[2] and Beaven[3] are probably descended from this. The structure of these kaputzen has been described by Henslow[4] and by Baillon[5] in the case of *H. trifurcatum*. In this variety the awns are wanting, and their place is taken by a hood-like structure produced at the apex of the paleae, in the pocket of which a single floret is placed. The structure of the floret is peculiarly variable. Generally speaking, it consists of two paleae enclosing perhaps a solitary ovary, or one or two stamens, or sometimes a

[1] Royle, *Botany of the Himalayan Mountains*, p. 418 and Pl. 97 (*H. aegiceras*).
[2] Koernicke, *ibid.*
[3] Beaven, *ibid.*
[4] Henslow, *Hooker's Journ. of Botany*, Vol. I. p. 33, Pls. II. and III. 1849.
[5] Baillon, *Bull. de la Soc. bot. de France*, Tome 1, p. 187 (1854).

perfect hermaphrodite flower. In *H. zeocriton*, var. *densum* (Kcke) the outer palea of the supernumerary floret itself may give rise to a second floret.

These florets are as a rule sterile, but in *H. distichum*, var. *setosum*, I have frequently met with a few fertile ones, and grown plants from the grains they produced. The structure is possibly a true epiphyllous flower.

On crossing these hooded varieties with those bearing normal, *i.e.* flowerless awns, the hybrids in all cases are hooded[1], the supernumerary floret being borne either on the apex of the palea or on an awn from a half to two inches in length. Up to the present I have raised the following examples:

H. Abyssinicum × *H. trifurcatum* (hooded) (Fig. 4 *a*), hybrid (Fig. 4 *c*).

H. spontaneum (Fig. 2 *a*) × *H. hexasticofurcatum* (hooded) (Fig. 2 *b*), hybrid (Fig. 2 *c*).

H. trifurcatum (hooded) × *H. nutans*.

H. trifurcatum (hooded) × *H. Steudelii*.

In each of these hybrids the hoods are as markedly developed as in the parent forms. The first generation from the hybrids consists of individuals with hoods and individuals with awns in the ratio of three of the former to one of the latter. Thus *H. trifurcatum* × *H. nutans* (F_2) produced 71 hooded and 23 awned plants, and the hybrid of unknown parentage already referred to, 205 hooded and 69 awned plants. The first generation from the remaining hybrids has still to be raised.

Barleys with these supernumerary florets, though probably monstrous, may be regarded as more fertile than those in which they are wanting, since there is always the possibility of their setting more grain. From this point of view, then, the more fertile form is dominant over the less fertile. Lessened fertility may then be a recessive character in the barleys, so that this case would resemble to a certain extent that of the sweet peas described by Bateson, in which the sterile forms behaved as recessives. It must however be admitted that we are dealing here with a different class of phenomena.

Up to the present, then, we have evidence that sterility, using the word in the broad sense already mentioned, may be a Mendelian character in the following cases:

(1) It may appear as a recessive,

(*a*) in the sweet pea hybrids described by Bateson;

[1] Compare Rimpau, *ibid.* Tschermak, *Deutsche Landw. Presse*, 14th Oct., 1903.

(*b*) in hybrids between "hooded" and awned barleys, where the more fertile hooded form is dominant over the less fertile awned form.

(2) As a dominant character when

(*a*) fully fertile varieties are crossed with those in which the lateral florets are reduced in size but hermaphrodite;

(*b*) when crossed with varieties in which the lateral florets contain stamens only;

(*c*) when crossed with varieties with sexless lateral florets;

(*d*) where varieties with small but fully fertile lateral florets are crossed with varieties with staminate or sexless lateral florets;

(*e*) where varieties with staminate lateral florets are crossed with varieties with sexless lateral florets.

VARIATION IN COMPOSITION OF THE SWEDE.

In Mr S. H. Collins's paper in Part I he puts forward a law by which the proportion of dry matter in a given swede crop may be deduced from a formula of the type $A = k + s + v + f$, where k is a constant and s, v, and f "factors" for season, variety, and farm respectively. In his section on "verification of results," p. 96, he states that his law "must be correct...if the two sets of figures "calculated" and "found" agree with one another as well as the duplicates of actual analyses."

This seems to me rather dangerous doctrine, since from one point of view it may mean that if the experimental error be only large enough it will cover the proof of any law that may be suggested. Nor is the example quoted in the same paragraph by Mr Collins reassuring; he gives a case where $A = 11{\cdot}23 - 06 + {\cdot}20$, and then proceeds to state that the average difference between duplicate samples amounts to 0·38. In other words, the average experimental error is nearly twice as large as one, and six times as large as the other, of the "factors" used in his calculations! Of course this may be an exceptional case, but Mr Collins's argument would be more convincing if he could give us some idea of the degree of accuracy to be expected in his various "factors" I have just worked out roughly a few cases by the usual method of least squares with the following results.

For the variety factors in the table (p. 103) for Holborn Elephant and Waterloo, the results are $0{\cdot}16 \pm 0{\cdot}105$ and $0{\cdot}20 \pm 0{\cdot}12$. For the season factor s, calculating from the mean results only as given in Table III, p. 95, I get a probable error of $\pm 0{\cdot}12$. Calculating from individual results, 1900 and 1904, the probable error becomes $\pm 0{\cdot}22$.

In one case also, for the so-called "farm factor," the relationship between Cockle Park and Eshott in 1903 appears to be

$$-0{\cdot}35 \pm 0{\cdot}13.$$

This would make a calculation run somewhat as follows, for, say, Holborn Kangaroo grown at Eshott in 1902 (an imaginary case),

$$A = 11{\cdot}23 + (0{\cdot}20 \pm 0{\cdot}12) + (0{\cdot}50 \pm 0{\cdot}12) + (-0{\cdot}35 \pm 0{\cdot}13).$$

Of course I may have happened upon extreme cases, but the figures seem to justify one in asking Mr Collins to review his results from the point of view of the relative magnitude of the "factors," and of the probable errors involved in their determination.

A. D. HALL.

VOLUME I OCTOBER, 1905 PART III

OXIDATION IN SOILS, AND ITS CONNEXION WITH FERTILITY.

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INTRODUCTION.

THE phenomena attending the absorption of oxygen by soils have been investigated by Déherain and Demoussy, and also by Wollny. An account of the work of the French chemists can be found in the *Annales Agronomiques*[1]. Their method was to place the soils under examination in a closed tube holding about 100 c.c and kept at constant temperature, then after a certain time to extract the gases and determine the carbon dioxide present. This was taken to be a measure of the amount of oxidation. The general results they obtained are as follows:

1. The quantity of carbon dioxide produced increases with the temperature to about 65° C, and then decreases. At higher temperatures (above 90°) it increases again.

2. It increases with the amount of water present up to a certain point, and then decreases. This optimum amount, however, varies from soil to soil.

3. It is greatly influenced by the state of division of the soil. Déherain and Demoussy recognise that the production of carbon dioxide only partially represents what the oxygen has done, but the results obtained in different experiments are considered to be comparable.

Wollny[2] independently investigated the problem somewhat more fully. His method was essentially the same; 100 gms. of soil were kept at constant temperature, and the carbon dioxide produced was estimated.

[1] *Ann. Agron.* Vol XXII. p. 305.

[2] *Die Zersetzung der organischen Stoffe*, 1897.

He obtained the results set out above, and the following additional ones:—

4. Oxidation is checked or altogether inhibited in presence of antiseptics.

5. It is increased by adding lime, and also, in some cases, by adding culture solutions.

The deduction was drawn that oxidation is mainly, if not entirely, bacterial.

The method is open to much criticism and to some serious objections. The implied assumption that the evolution of carbon dioxide is proportional to the amount of oxygen absorbed is nowhere proved; the presence of the carbon dioxide formed may reasonably be supposed to interfere with oxidation, and, further, the extraordinary power some soils possess of absorbing carbon dioxide introduces errors. Moreover the experiments are by no means easy to carry out, and it is probably for this reason that the rate of oxidation has so far found no practical application.

Method of Investigation.

Instead of determining the carbon dioxide produced, the author has measured the actual amount of oxygen taken up. The apparatus, which is extremely easy to make, consists of a flask of about 100 c.c. capacity with two tubes sealed into its neck. The wider of these (*A*, Fig. 1) is bent at right angles and terminates in a bulb *B*, higher up is the narrower one, *C*, of about 4 mm. diameter, also bent at right angles, but open at the end A weighed quantity of the air-dried soil is introduced into the flask, a definite amount of water is added, and the neck of the flask is either sealed up or closed with a very well-fitting rubber cork. Potash solution (1 KOH : $2H_2O$) is run into *B* by the little side tube *D*, which is then sealed, and the end of *C* is dipped under mercury, thus converting it into a gauge. The apparatus is now placed in a water-bath at constant temperature, oxygen is absorbed, and doubtless a complex reaction takes place, but the only gas likely to be set free from ordinary soils is carbon dioxide, and this is so rapidly absorbed by the potash that at any given moment the quantity present in the free state is negligible.

The absorption of oxygen is indicated by the rise of mercury in *C*, and from a measurement of the height of the column above the surface the amount of oxygen taken up is readily found. A cathetometer and millimetre scale are used for this purpose. In practice six or seven

soils can very well be examined simultaneously, the experimental vessels are made of approximately the same size, they are numbered and calibrated, and the potash solution run into B is in such quantity that the volume of air left is the same in all the vessels. They are then fixed in a curved water-bath, so that all the gauges are in focus simultaneously.

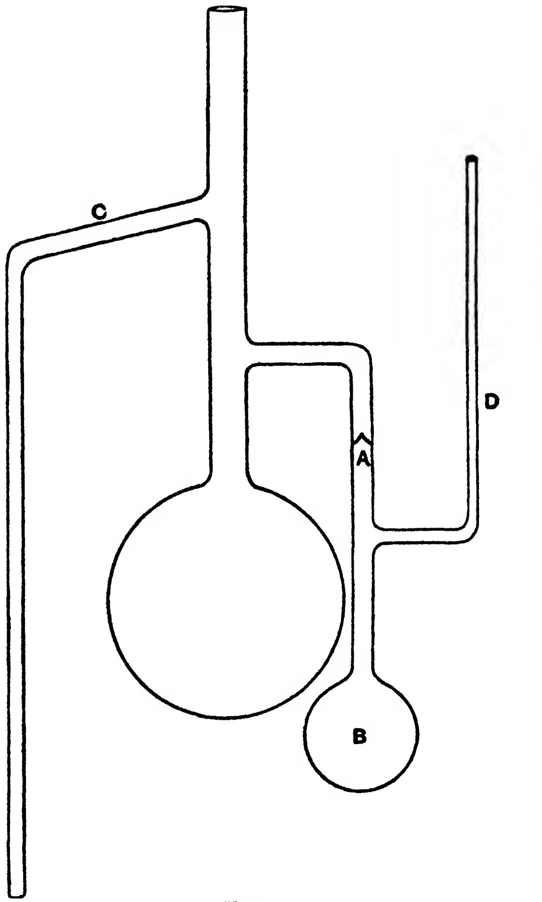

FIG. 1.

The disposition of the apparatus is shown in Fig. 2. Readings are facilitated if at the outset the bulb B is slightly warmed to expel some of the contained air, the mercury column then starts well above the surface, and a sudden drop in the barometer does not have the effect of depressing the mercury to a point where it could not be read.

Absorption is slow, lasting some days or even weeks, and in order to obviate difficulties attending changes of temperature and pressure it is necessary to have in the bath a control apparatus containing no soil.

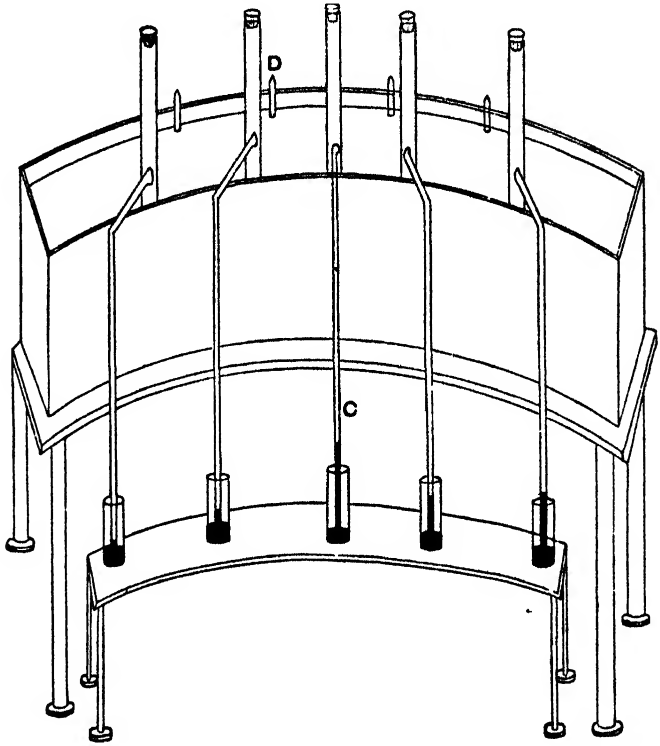

Fig. 2

The movements of mercury in this case dep[illegible]t[illegible]y on changes of temperature and pressure and give a correction whic[illegible]adily applied to the other vessels. The method of reducing the rea[illegible]gs will be seen from the following example:—

Control Flask.

	Height of mercury above surface	Change produced by alteration in temperature and pressure since beginning
Jan. 25	83·4 mm.	
Feb. 2	73·9 ,,	−9·5
,, 14 .	88·9 ,,	+5·5

Soil No. 1 in Flask 1.

Weight of air-dried soil ...	10 grams	Total volume of apparatus...	107·5 c.c.
Water added..................	2 c.c.	Potash run into B	11·0 c.c.
		Volume of air and soil	96·5 c.c.

	Height of mercury above surface	Corrected for change of temperature and pressure	Actual absorption of oxygen
Jan. 25 ...	50·5 mm.		
Feb. 2 ..	57·3 „	66·8 mm.	16·3 mm.
„ 14 ..	83·7 „	78·2 „	27·7 „

Soil No. 2 in Flask 2.

Weight of air-dried soil ...	10 grams	Total volume of apparatus ..	104·7 c.c.
Water added	2 c.c.	Potash run into B	8·2 c.c.
		Volume of air and soil	96·5 c.c.

	Height of mercury above surface	Corrected for change of temperature and pressure	Actual absorption of oxygen
Jan. 25 ..	28·3 mm.		
Feb. 2 .	29·3 „	38·8 mm.	10·5 mm.
„ 14 .	55·1 „	49·7 „	21·4 „

The experiment actually began on Jan. 24th, but the apparatus was left for 24 hours to ensure it taking the temperature of the bath. The corrected value on Feb. 2nd is obviously obtained by adding 9·5 and on Feb. 14th by deducting 5·5. The absolute weight of oxygen absorbed can of course be readily calculated from the diminution of oxygen pressure recorded in the third column, but for our present purpose there is no advantage in doing this; the experiments are all carried out under comparable conditions and the figures are used as they stand.

Preparation of the soil. The samples, taken with the usual precautions, are spread out on trays to dry sufficiently to allow them to be pulverised and sifted. The drying should not go too far, and the same sized sieve must be used in all experiments. For accurate work the sifted samples must be kept over water for 24 hours, but for ordinary purposes this is not necessary. In all the experiments recorded here 10 grams of air-dried soil were used, and for a given set of experiments the amounts of distilled water added were constant.

The temperature in all cases was about 17° C.

Influence of various Factors on the Rate of Oxidation.

1. The quantity of soil taken.

Quantity of soil	Oxygen absorbed in	
Loam, Rothamsted	7 days	48 days
5 grams	1·73 mm.	8·81 mm.
10 ,,	2·41 ,,	12·60 ,,

Quantity of soil	Oxygen absorbed in		
Chalky loam, Wye	6 days	27 days	40 days
5 grams	5·6 mm.	13·6 mm.	20·53 mm.
10 ,,	8·53 ,,	22·6 ,,	30·04 ,,

Oxidation is not proportional to the weight of the soil, but more probably is related to the extent of the surface.

2. Amount of water present. (*a*) A fairly stiff loam was used.

	Oxygen absorbed in	
	7 days	48 days
Air-dried soil, containing 6·33 °/₀ "hygroscopic" water	*nil*	*nil*
The same soil, containing 10 °/₀ added water	1·73 mm.	8·81 mm.

(*b*) Chalky soil, Wye.

	Oxygen absorbed in 23 days
Air-dried, containing 7·4 "hygroscopic" water	6·5 mm.
20 °/₀ added water	21·6 ,,
25 °/₀ added water	27·7 ,,

A preliminary trial is always necessary in adding water because some soils show a critical point beyond which a small addition of water causes the whole to form a sticky mass.

Added water	Oxygen absorbed in	
	8 days	following 6 days
20 °/₀, soil still loose	9·94 mm.	10·25 mm.
21 °/₀, sticky mass just forming	5·28 ,,	9·05 ,,
21·5 °/₀, sticky mass completely formed	slight evolution of gas	9·00 ,,

After the first abnormal period oxidation proceeds regularly enough, but this particular quantity of water is to be avoided.

3. Influence of lime and calcium carbonate.

	Oxygen absorbed in	
	8 days	following 21 days
Sandy soil alone	2·40 mm.	8·47 mm.
,, + ·8 °/₀ CaO...	1·46 ,,	5·00 ,,

The addition of lime at first delays oxidation, but after a time it is converted into the carbonate, and oxidation is accelerated.

	Oxygen absorbed in	
	4 days	31 days
Fertile alluvial soil	28·21 mm.	109 07 mm.
,, + 1 °/₀ $CaCO_3$	29·61 ,,	124·33 ,,
,, + 2 °/₀ $CaCO_3$	30·27 ,,	131·39 ,,

4. Surface soil compared with the subsoil.

Deep alluvial soils, situated on Romney Marsh.

	Oxygen absorbed in	
	7 days	28 days
No. 1. Surface soil (0—6″)	26·27 mm.	61·73 mm.
Subsoil (6″—12″)	19·4 ,,	38·53 ,,
No. 2. Surface soil (0—6″)	13·21 ,,	37·94 ,,
Subsoil (6″—12″)	8·0 ,,	21·6 ,,
Light sandy soil. Surface soil (0—6″) ...	2·92 ,,	8·66 ,,
Subsoil (6″—12″)	1·59 ,,	1·86 ,,

Rothamsted soil. Samples from fallow piece in Little Hoos field.

Taken at 10 cm. depth	15·00 mm.
,, 20 ,, ...	13·07 ,,
,, 30 ,, ...	*nil*

The conditions obtaining in the subsoil are evidently not favourable to oxidation even when there is an ample supply of oxygen. This may probably be connected with the smaller amount of organic matter in the subsoil and its more resistant character as compared with that in the surface soil.

5. Influence of sterilisation.

	Oxygen absorbed in 10 days
Fertile loam	27·19 mm.
„ heated for 30 minutes at 130°......	8·19 „
„ +1 °/。 mercuric chloride....	7·18 „

Oxidation is not inhibited, but is greatly reduced, by these processes.

It is possible to stimulate oxidation, but this question, and others dealing more fully with the mechanism of the process, will be reserved for a future communication.

6. Age of the sample. Chalk-loam, Wye.

	Oxygen absorbed in		
	6 days	27 days	40 days
Sample taken Jan. 23rd, and kept till May in air-dried condition	7·06 mm.	22·60 mm.	30·40 mm.
Sample taken May 10th, air-dried and used at once...............	8·53 „	22·60 „	30·04 „

The sample showed no deterioration when well preserved for three and a half months.

Fertility and the Rate of Oxidation.

From the results set out above it is evident that the same factors which increase the productiveness of the soil—temperature, water, calcium carbonate, etc.—also increase the rate of oxidation, whilst those inimical to the one—sterilisation, and the general conditions obtaining in the subsoil—also decrease the other. If both are influenced to somewhat the same extent by these different factors, then the rate of oxidation should afford a valuable indication of the relative fertility of different soils.

A number of soils of known fertility have been examined. In each series the investigation has been confined to soils of the same type from similarly situated and closely adjacent fields. Only in this way can the disturbing effect of climate and the physical structure of the soil be eliminated.

ARABLE SOILS.

1. Soils of equal fertility from the same field.

The samples were taken from a level field on the College farm (chalky loam) known from its crop yields to be fairly uniform.

	Oxidation in 22 days
Sample 1	22·60 mm.
„ 1	21·86 „
„ 2	21·5 „

2. Soils of different fertility.

A. Sandy Soil.

(*a*) Samples from the Woburn Experimental Station (Lower greensand formation) were very kindly prepared for me by Mr S. F. Ashby, to whom I am greatly indebted also for the Rothamsted samples used in another series of experiments.

Sample No.	Name of Field	History	Average of last 4 crops (bushels)	Oxidation in 17 days (mm.)
7	Stiff Oxford Clay	Wheat stubble	—	23·2
2	Road piece	After wheat, preceded by mangolds, fed with cake or corn	—	18·7
5	Lansome Field	Barley 1904 after wheat 1903 and mustard ploughed in (1902), mineral manure	26·5	14·1
6	„	Barley after wheat and tares ploughed in (1902), mineral manure	17·2	10·2
4	„	Barley after wheat and tares ploughed in (1902), no mineral manure	16·1	8·2
8	Stackyard Field	Continuous wheat, unmanured	9·2	8·2
9	„	Continuous wheat, ammonium salts containing 50 lbs. ammonia only	6·3	7·8

In a letter to me on the fertility of these plots, Dr Voelcker, who has kindly taken the greatest interest in these determinations, says:—"No. 7, stiff Oxford clay is undoubtedly the richest soil of the number. I should certainly call Road piece (No. 2) the second best of the series. As between Lansome Field Nos. 5, 6, 4, and Stackyard Field, Nos. 8 and 9, there is, I should say, not a great difference as regards inherent fertility, but, taking the samples selected, the individual ones from Lansome are, no doubt, at present more fertile than the selected ones from Stackyard Field."

Turning now to the oxidation results, the order in each of the groups is the same as for the fertility; the same order appears, too, when the groups are compared with one another. The great fall in the crop on Stackyard Field is probably rather due to secondary causes than to deficiencies in the soil.

(*b*) Sandy Soil from Bramley, Surrey.

In a large fruit plantation (chiefly gooseberries) owned by Messrs E. Ellis and Son, there was a portion decidedly less productive than the rest, although the manuring and cultivation had been in all respects the same.

The amounts of oxidation after 8 days were:

	Fertile portion (*a*)	Less fertile portion (*b*)
Surface soil	2·92 mm.	2·40 mm.
Subsoil	1·59 „	·40 „

At the end of four weeks the differences were more accentuated:

	Fertile portion (*a*)	Less fertile portion (*b*)
Surface soil	8·66 mm.	5·87 mm.
Subsoil	1·86 „	*nil*

The poorness of (*b*) is therefore due in part at any rate to some fault inherent in the soil itself and not merely to its situation or water supply, the subsoil in particular being apparently absolutely sterile. An obvious advantage of the method is that it enables one to localise the trouble.

B. Loams.

With the kind permission of Mr A. D. Hall samples were obtained from Rothamsted.

Agdell Field, Rotation experiment.

No.		Manuring	Oxidation in	
			4 days	6 weeks
			mm.	mm.
A_3	Roots fed on ground: beans or clover...	minerals + nitrogen	3·86	15·40
A_2	„ „ „ „ ...	minerals	2·66	11·68
A_1	„ „ „ „ ...	no manure	2·27	9·00

Reference to the Rothamsted memoranda shows that this is also the order of productiveness.

Broadbalk Wheat Field.

Plot	Manuring	Average crop	Oxidation in	
		bushels	7 days	6 weeks
2 B	Farmyard manure, 14 tons	35·6	6·93 mm.	37·74 mm.
19	Rape cake containing 92·6 lbs. nitrogen	26·7	3·74 ,,	12·73 ,,

Barnfield Mangold plots.

Plot	Manuring	Average crop	Oxidation in		
Series 5		tons	8 days	14 days	6 weeks
Plot 1	Farmyard manure + rape cake	24·12	9·94 mm.	20·19 mm.	41·69 mm.
,, 4	Minerals + rape cake	21·39	7·27 ,,	16·00 ,,	

In all cases the indications given by this method completely accord with the crop yields.

C. Chalk Soils.

These were taken at Wye and included samples from:—

(1) An old pasture land now broken up and put into oats (Marriage Farm).

(2) The College hop garden, which receives each autumn about 20 loads of dung to the acre.

(3) A very similar plot, which received the same quantity of dung last autumn preparatory to a mangold crop, but is not generally as well treated as (2).

(4) A poorer plot, barley stubble, previous to which roots had been folded off.

	Oxygen absorbed in		
	6 days	27 days	40 days
1. Old pasture...... ..	18·07 mm.	51·4 mm.	64·04 mm.
2. Hop garden.........	8·66 ,,	24·13 ,,	32·40 ,,
3. Mangold plot	8·53 ,,	22·6 ,,	30·04 ,,
4. Barley stubble......	7·26 ,,	21·46 ,,	29·53 ,,

As a result of some years' experience with the College soils, Mr K. J. J. Mackenzie, the lecturer on Agriculture, considers that the differences between 2, 3, and 4, are probably not great, but that they

should be placed in the above order. 4 is thinner than 3, and therefore dries out more readily, causing the difference in yield.

The fertility of the old pasture soil cannot yet be gauged, but it seems remarkable that the rate of oxidation should come out so much higher than the others, which have been arable land for many years.

The order in which the soils appear, and the differences between the observed rates, fit in with what is known of their productiveness.

Pasture Soils.

In some cases the method has worked satisfactorily, but in others it has failed. There is considerable difficulty in deciding whether the poorness of a pasture is due to bad management allowing weeds to crowd out the grasses, and also it is quite possible that the conditions of fertility in arable and pasture fields are not identical.

I. Gault Pastures, Cambridge.

Professor T. H. Middleton kindly sent me three pasture soils arranged in the following order:

1. Old pasture ploughed up three months earlier. Small paddock closely grazed by cattle.
2. Pasture on the University Farm.
3. Very poor old grass field, which has probably been neglected.

Professor Middleton added that he had not himself seen No. 3.

	Oxygen absorbed in			
	2 days	4 days	10 days	38 days
No. 1. Good....	4 67 mm.	11·26 mm.	27·19 mm.	57·37 mm.
No. 2. Poorer	3·0 ,,	7·45 ,,	17·45 ,,	37·03 ,,
No. 3. Reported poor ..	6·8 ,,	12·06 ,,	24·66 ,,	56·43 ,,

At a later date Professor Middleton wrote saying that he had been to field No. 3 and considered the soil certainly better than No. 2. He placed the order of fertility so far as the soils were concerned as

No. 1,
No. 3,
No. 2,

which corresponds with the order of oxidation.

No. 3 shows a curious change in its behaviour, oxidising first more rapidly, afterwards more slowly than No. 1.

II. Alluvial Pastures, Romney Marsh.

Soils were taken from Orgarswick, the farm of H. J. Clements, Esq.

1. "Fatting Field" carries and fattens 6 sheep per acre in summer and 2½ in winter. It is too strong for lambs.

2. "Jeffry's 10 acre Field" is not as good, but had been mismanaged before Mr Clements took it.

3. "Fresh Field" was arable till 5 years ago, yielding 7 or 8 quarters of wheat, 14 of oats, and 7 of beans. It was laid down to permanent pasture by Mr Clements' predecessor, but an unsuitable mixture was used, and the appearance of the field is now pitiable, when one thinks of its past history.

4. "Middle Field." The poorest of the lot. It carries 4 sheep with lambs in summer, and 2 in winter, but it does not fatten them.

These fields all adjoin one another, and there is no way of accounting for the marked difference between Nos. 1 and 4. Similar cases, however, occur not infrequently in Romney Marsh.

	Oxygen absorbed in			
	4 days	6 days	20 days	31 days
No. 1. Fatting Field	18·35 mm.	27·75 mm.	69·00 mm.	102·27 mm.
No. 2. Jeffry's 10 acre .	26·07 ,,	39 87 ,,	79·47 ,,	98·46 ,,
No. 3. Fresh Field	13 48 ,,	17·55 ,,	38·2 ,,	53·08 ,,
No. 4. Middle Field	28·21 ,,	43·54 ,,	95·13 ,,	109·07 ,,

No. 4 is abnormal throughout, Nos. 1 and 2 show the same peculiarity as in the gault soils On the 31st day Nos. 1, 2, and 3, come out in their proper order, but No. 4 is altogether in the wrong place, and on the earlier days No. 2 is also in the wrong place.

At present I do not consider the method is suitable for pasture land; it appears, however, to give useful results for arable land. In the foregoing pages I have included every reading with every soil examined; it will be seen that the result invariably accords with the history of the soil, excepting in the pasture soils.

DISCUSSION OF THE METHOD.

Signification of the results. The rate of oxidation depends on all the factors influencing the fertility of the soil, but the relationship is complex, and in a given series of soils these factors interact to so great an extent that it is not as a rule possible to directly connect the oxidation results with any one of them. This is well seen in the Woburn

soils; determinations of the carbon, nitrogen, and calcium carbonate were made and are set out below. The soils are arranged in their order of oxidation, but neither of these shows any simple connexion with the other factors.

Order of fertility and oxidation (see page 269)	Nitrogen	Carbon	Ratio C : N	Loss on Ignition	"Hygroscopic water" (*i.e.* lost at 95° but not at 15°)	Calcium carbonate
7	·2520	2·534	10·06	8·73	4·12	·0206
2	·1724	1·765	10·24	5·31	1·60	·0720
5	·1217	1·193	9·80	4·17	·976	·027
6	·1322	1·242	9·32	3·22	1 16	·051
4	·1094	1·181	10·81	3·46	1·04	·0084
8	·0604	1·389	23·0	4·07	1·16	·0042
9*	·1022	1·290	12·62	4·58	1 18	*nil*

* It was discovered afterwards that the sample of No. 9 sent for analysis came from the *barley* plot, whilst that previously investigated was from the *wheat* plot. The two are in the same field, not 50 yards apart, similarly situated and with the same manurial and crop history. It is reasonable to suppose that the analytical data would be much the same in both.

The percentages are calculated on the air-dried soil.

Organic Matter. It is impossible to estimate the precise amount of organic matter in the soil, it is usually taken as being proportional either to the loss on ignition or to the quantity of carbon present, but the two methods do not lead to the same result. Placing the soils in descending order we get

(1)	from loss on ignition	7	2	9	5	8	4	6,
(2)	from carbon determinations	7	2	8	9	6	5	4,
	order of oxidation	7	2	5	6	4	8	9.

No. 8 contains so little nitrogen that the percentage of carbon in its organic matter must be unduly high, and hence a false position is assigned. No. 6, which was green manured with tares, contains more carbon and also more nitrogen than No. 5, where mustard was ploughed in; but if the loss on ignition figures have any value they indicate that No. 5 contains more organic matter than No. 6. If the extra hydrogen and oxygen in No. 5 denote a further stage in the hydrolysis of the organic matter, we should have an explanation of the higher rate of oxidation of No 5 than of No. 6. But the ignition figures have to be interpreted with great caution, and deductions must not be carried too far. Dr Voelcker in his Report for 1902 has called attention to the special interest attached to these two plots.

The high position of No. 9 in both lists is easy to understand, excessive ammoniacal manuring has made the soil acid to litmus paper and largely sterile to bacteria. Barley fails, but spurry flourishes, and, as oxidation is not vigorous, organic matter tends to accumulate.

Thus although the values obtained and the order assigned in the above list may be reconciled with one another and with the history of the plots, they would not enable useful deductions to be drawn as to the productiveness of the plots.

It is quite evident that the rate of oxidation is not proportional to the amount of organic matter present.

Nitrogen. Arranging as before in descending order of magnitude

we get	7	2	6	5	4	9	8,
whilst the order of fertility is	7	2	5	6	4	8	9.

The order in both cases agrees fairly closely. Nos. 5 and 6 are transposed, and the analyst would in all probability fall into error over these two. No. 9 also appears in its wrong place, but the acid reaction of the soil and its manurial history would prevent any mistake being made as to its fertility. It is indeed remarkable that No. 9 does not contain more nitrogen considering the small crops grown and the large amount of ammonia annually supplied. Even on the stiffer soil at Rothamsted, however, it is not found that ammonia persists for any length of time, still less would it be likely to accumulate on the light Woburn soil.

It would not be justifiable to conclude that the rate of oxidation is proportional to the amount of nitrogen present, for the above exceptions are of very real significance. More probably nitrogen is one of the predominant factors determining the fertility of these particular soils, and if that is so, one would expect it to show a certain parallelism with the rate of oxidation. But the two are fundamentally distinct, and the present agreement is purely accidental.

Ratio of Carbon to Nitrogen, and vice versâ. The order of magnitude is:

ratio $C:N$	8	9	4	2	7	5	6,
ratio $N:C$	6	5	7	2	4	9	8,
rate of oxidation	7	2	5	6	4	8	9.

At first sight a greater agreement might have been expected. The losses during decay fall more on the carbon than on the nitrogen, and a decrease in the ratio $C:N$ might be anticipated. Thus a high ratio would indicate fresh organic matter, and a low ratio the residual, and

presumably less easily decomposable, substances. The assumptions are not sound, however. Bearing in mind that the amount of carbon is ten times as great as that of nitrogen it is evident that the quantities of the two elements removed during the process must be in the same proportion if the ratio is even to remain constant. Nor is it certain that the residual substances would be more resistant to decomposing agents. Hydrolysis almost certainly proceeds *pari passu* with oxidation, and the hydrolysed products might be more, and not less, easily attacked. The rate of decomposition is associated rather with configuration than with percentage composition

It is not surprising, then, that the ratio $C : N$ leads to no useful result in this case. No. 8 is altogether abnormal, the sample may not have been a good one, but this seems hardly likely. No. 9 is high, but the others give a value curiously near to the Rothamsted ratio, in spite of the great difference between the soils.

Calcium carbonate. The amounts of this substance are in the following order:

	2	6	5	7	4	8	9,
omitting 7		2	6	5	4	8	9,
order of oxidation	7	2	5	6	4	8	9.

No 7 is a stiff clay, and hardly comparable with the others Omitting this, the order is nearly the same for the percentage of calcium carbonate as for the rate of oxidation, and indeed the close connexion between these has already been shown. The remarkable feature is that the most productive plots, instead of having their stores of calcium carbonate depleted by the large crops they bear, actually contain more of this substance than the less fertile plots carrying smaller crops. How this has been brought about, and to what extent it is connected with their extra fertility, are questions we cannot now discuss.

Hygroscopic water. This may be taken to represent the water retained by the soil and not available for plant use. The order in which the soils are placed is

	7	2	9	$\left.\begin{matrix}6\\8\end{matrix}\right\}$		4	5,
carbon	7	2	8	9	6	5	4,
order of oxidation	7	2	5	6	4	8	9.

To some extent this order resembles the one derived from carbon determinations, and no doubt the hygroscopic water is connected with

the amount of organic matter. But until we have a fuller knowledge of the subject, there is no advantage in pursuing the somewhat elusive relationship between hygroscopic water and rate of oxidation.

The above discussion suffices to show that no single factor regulates the rate of oxidation. In this particular case the amounts of nitrogen and of calcium carbonate show a closer relationship with it than do the others, and with these soils they may perhaps be regarded as the dominant factors; but with other soils other conditions seemed to have a controlling effect.

In the foregoing pages no explanation has been offered of the connexion between oxidation and fertility. The method stands on a purely empirical basis—the same factors that influence fertility also influence the rate of oxidation, and apparently to the same extent. This basis is quite sufficient to justify its use in soil analysis quite apart from any explanation.

It may be of interest briefly to outline the hypothesis, which, in the view of the author, fits in best with all the facts. Presuming that the crops grown are adapted to the climate and to the general conditions prevailing, a fertile soil may be defined as one in which reactions take place so rapidly that the plant is abundantly supplied with food. Reactions may be hastened in three ways, the temperature may be raised, the concentration increased, or a catalytic agent employed; as a rule the first two methods are inapplicable in nature; high temperatures are obviously out of the question; the concentration of the soil solution cannot greatly increase, or its osmotic pressure becomes too high for the plant; and generally speaking, reactions in nature are accelerated by catalytic agents. Little is known of the catalytic action of the inorganic constituents of the soil, but there can be no question that the innumerable micro-organisms invariably present secrete enzymes which are powerful catalytic agents. When the concentration of the enzyme is small, as in the soil, action is more or less proportional to the amount present, and as enzymes in turn depend on the presence and activities of bacteria, moulds, fungi, etc., the number of these will be related to the amount of chemical action taking place. As most of the organisms in the surface layer are probably aerobic, a measure of their activity can be obtained from the rate at which oxygen is absorbed. A large oxygen absorption indicates a high activity of the micro-organisms, rapid chemical changes in the soil, and consequently a high state of fertility.

The above dynamic definition differs essentially from the ordinary static definition, according to which productiveness is connected with the quantity of "available" food actually present at a given moment. It will, however, be found more useful.

The chemical actions taking place in the soil include the breaking down of organic matter and the simplification of phosphatic and potassic substances referred to by Ingle[1]. The former are mainly enzymic or bacterial, the mechanism of the latter is not so clear. Some of the steps involved in the breaking down of the organic matter have been examined, and methods of soil analysis based upon them have been published. Thus Remy[2] measures the putrefying power of the soil, *i.e.* the rate at which organic matter is broken down to ammonia; Omeliansky[3] measured the rate at which ammonia changes to nitrite and the nitrite to nitrate; Ashby simplifies matters by running from ammonia direct to nitrate without stopping at the nitrite stage[4]; and Beijerinck[5] estimates the power of assimilating nitrogen. Whilst these determinations throw a flood of light on the separate bacterial processes taking place in the soil they cannot be expected to give much information about the total action, which according to the view taken here plays so important a part in determining fertility. The determinations are made in culture solutions so arranged as to favour one particular organism at the expense of the rest, optimum conditions are secured and maximum velocities obtained. The sum of these is not related to the actual speed of decomposition in the soil, any more than the sum of the velocity of a pony at a point to point race and of the Continental boat train is connected with the time actually required to drive to the station and make a cross country journey involving several changes. The study of the maximum speeds is of course essential for a complete solution of the problem, but some integrating method is also wanted to measure the total change actually taking place. The determination of the rate of oxidation is suggested as giving a useful indication of this total change, and therefore of the relative fertility of different soils.

It is clearly recognised that this view of fertility is not complete; no direct account is taken of the temperature and moisture conditions,

[1] *Journ. Chem. Soc.* 1905, Vol. LXXXVII. 43.
[2] *Cent. fur Bakt. und Parasit.* 8, 660.
[3] *Ibid.* 5, 539.
[4] *Jour. Chem. Soc.* 1904, Vol. LXXXV. 1158.
[5] *Cent. für Bakt. und Parasit.* VII. 568.

which, in these experiments, were kept constant. The soil itself, isolated from its surroundings, is here being dealt with, and in interpreting the results it must be remembered that the surroundings may profoundly modify the productiveness of a naturally fertile soil. The ideal method would no doubt be to correct the oxidation values obtained in the laboratory by making simultaneous determinations *in situ*, the modifying effect of the conditions actually prevailing in the field would then be directly determined; unfortunately no practicable method of doing this has yet been devised. At the same time it is often of advantage to know in a particular case whether non-productiveness is due to a deficiency in the soil itself, or to some other condition, and here the method can give useful information.

CONCLUSIONS.

1 The rate at which oxygen is absorbed by a soil can be easily and accurately measured by the method here described.

2. The rate increases with the temperature, the amount of water (up to a certain point), and the amount of calcium carbonate, and is favoured by the conditions obtaining in the surface soil as opposed to those in the subsoil.

3. These are also the conditions favouring fertility. It is found that with different soils of the same type the rate of oxidation varies in the same way as the fertility, and may be used to measure it. Pasture soils are at present excluded, however.

4. It is suggested that the oxygen absorbed measures the total action of the micro-organisms, which, by producing enzymes and in other ways, hasten decomposition in the soil. Plant food is thus produced, and the general conditions are rendered more favourable for plant life. *Ceteris paribus*, the more rapid these changes the more productive the soil will be.

THE AMOUNTS OF NITROGEN AS AMMONIA AND AS NITRIC ACID, AND OF CHLORINE IN THE RAIN-WATER COLLECTED AT ROTHAMSTED.

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At the time of the commencement of the Rothamsted experiments very little was known as to the amounts of combined nitrogen and other substances present in rain-water.

Marggraf (74) found nitric acid, chlorine and lime in rain-water collected during the winter of 1749–50, and, subsequently, in snow. These analyses, which are probably the earliest[1], were followed by those of Bergman (15) who detected the same substances both in rain and snow[2]; whilst somewhat later de Saussure (99) noticed the presence of ammonia in the atmosphere. Between 1820 and 1825 several analyses of rain-water were made. Hermbstaedt (54) detected organic matter, Mulder (84) and Zimmermann (125) found chlorine and several other substances in rain-water collected at Utrecht and near Giessen; whilst von Liebig found sometimes nitric acid and invariably ammonia in a number of samples which had been collected by Zimmermann. Brandes (24) determined the amount of total solids and detected the presence of chlorine, sulphuric acid, ammonia and other substances. By this time chlorine had already been determined by Dalton (37) in rain-water collected in Manchester. The first determinations of ammonia seem to be those of Payen (47) in 1845–6. From that date to 1855

[1] Evelyn, in his *Philosophical Discourse of Earth* (London, 1676), speaks of rains and dews as being "impregnated with Celestial Nitre" (p. 98), and of "nitrous spirits descending with their baulmy pearls" (p. 174). This does not of course indicate that nitrates had actually been detected in rain, as the terms nitrous air &c. were applied at this period—the time of Mayow's and Hooke's experiments on combustion—to what is now known as oxygen.

[2] "*Nivales* aliquantulum calcis salitae cum exiguis acidi nitri vestigiis in sinu fovent... *Pluviales* iisdem plerumque materiis inquinantur, sed majori dosi" (*Opuscula*, I. 84).

numerous analyses of rain-water were made, chiefly in France, and although many of the determinations were then, and some even much later, made without reference to the magnitude of the rainfall, some, as for instance those of Boussingault and Barral, were made in measured amounts of the total fall, so that it became possible for the first time to estimate how much of the constituents determined was supplied to a given area of land in a given period.

During the last fifty years analyses of the rain have been made in most European countries and in many other parts of the world. With few exceptions, however, the analyses extend over very short periods and partly for this reason the results are frequently conflicting.

The earliest analyses of Rothamsted rain were made in 1853–4, when the nitrogen in the form of ammonia was determined (63). Further determinations, both of ammoniacal and nitric nitrogen, were made by Way in 1855 and 1856 (121). These earlier results have already been fully discussed elsewhere (64), but to make the present record complete they are given in Appendix Tables III and IV, which contain the whole of the results relating to nitrogen obtained up to the end of the harvest year 1904–1905.

The determinations of ammonia in monthly samples of the rain were recommenced in 1877, and were continued with some interruptions until December, 1885 Since January, 1888, however, ammonia has been regularly determined each month.

Nitric nitrogen has been determined uninterruptedly since September, 1886, for some months by Schloesing's method and, subsequently, by Williams' zinc-copper couple method[1]. Chlorine has been determined each month since June, 1877 (Appendix Table V); and sulphuric acid, in mixed samples, representing winter and summer rain, from 1881 to 1887 (65 and 117).

Besides the monthly samples of rain, a large number of single samples have been analysed at Rothamsted (64), and in addition about 80 samples were analysed by the late Sir Edward Frankland (44).

NITROGEN AS AMMONIA AND AS NITRATES (AND NITRITES) IN ROTHAMSTED RAIN.

The average amounts of nitrogen in the forms of ammonia and nitric (and nitrous) acid in the Rothamsted rainfall during the thirteen harvest years, 1888–9 to 1900–1, is 3·84 lbs. per acre per

[1] *Trans. Chem. Soc.* 1881, 39, 100. For the minutiae of this and other methods employed at Rothamsted in the analysis of rain-water see Warington (118).

+ organic N = 4·7.

annum, the relative amounts of ammoniacal and nitric nitrogen being 70 and 30 per cent. of the total. The greatest amount of nitrogen in these forms during the above period was 4·43 lbs. (1899–1900), and the lowest amount 3·31 lbs. The variations from year to year (see Table 1)

TABLE 1.

Nitrogen as Ammonia and Nitric Acid in Rain-water collected at Rothamsted.

September 1 to August 31	Rainfall	Nitrogen						
		Per million		Per acre			% of Total	
		as NH_3	as N_2O_5	as NH_3	as N_2O_5	Total	as NH_3	as N_2O_5
	inches			lb	lb.	lb.		
1853–4*	29·01	0·79	—	5·20	—	—	—	—
1855**	29·17	0·88	0·11	5·82	0·72	6·54	89·0	11·0
1856**	27·22	1·18	0·12	7·28	0·76	8·04	90 5	9·5
1881–2	32·31	0·33	—	2·443	—	—	—	—
1882–3	34·71	0·34	—	2·665	—	—	—	—
1883–4	25·77	0·40	—	2·334	—	—	—	—
1884–5	26·78	0·37	—	2·240	—	—	—	—
1886–7	23·61	—	0 138	—	0·736	—	—	—
1887–8	30·50	—	0 116	—	0·803	—	—	—
1888–9	30 09	0·412	0·134	2·806	0·911	3·717	75·5	24·5
1889–90	27·43	0·445	0·119	2·762	0·741	3·503	78 8	21·2
1890–1	23·41	0·483	0·195	2 560	1·033	3·593	71·2	28·8
1891–2	29·68	0·466	0 185	3·130	1·240	4·370	71·6	28·4
1892–3	28·94	0·535	0·217	2·914	1·185	4·099	71·1	28·9
1893–4	29 55	0·381	0 131	2·549	0·878	3·427	74·4	25·6
1894–5	28·94	0·364	0·161	2·397	1·068	3·465	69·2	30·8
1895–6	24·37	0·484	0·216	2·670	1·193	3·863	69·1	30·9
1896–7	37·24	0·350	0·160	2·947	1·346	4·293	68·6	31·4
1897–8	19·51	0·516	0·234	2·279	1·032	3·311	68·8	31·2
1898–9	24·69	0·443	0·228	2·474	1·276	3·750	66·0	34·0
1899–1900	31·02	0·431	0·200	3·028	1·401	4·429	68·4	31·6
1900–1	24 30	0·498	0·250	2·737	1·375	4·112	66·6	33·4

* March to February. ** January to December.

probably depend, in part, on the distribution of the rainfall, but seem to have no very definite relation to the total annual amount of rain. The lowest amount of nitrogen found during this period was, however, coincident with the lowest rainfall (19·51 inches in 1897–8). The

large amounts of nitrogen found in the rain collected in the years 1853–6, are evidently mainly due to the ammonia results being far too high. As has been pointed out elsewhere (64), the methods employed at that time left a good deal to be desired.

The amounts of nitrogen in the monthly samples of rain depend partly on the temperature and partly on the amount of rain. The smallest amount of nitrogen is found in February, being coincident with the lowest rainfall, whilst the largest amount occurs in August, when, in addition to an increased temperature, there is also a large amount of rain only exceeded in October.

TABLE 2.

AVERAGE MONTHLY AMOUNTS OF NITROGEN AS AMMONIA AND NITRIC ACID IN ROTHAMSTED RAIN.

1888–9 to 1900–1	Rainfall	Nitrogen						
		Per million		Per acre			% of Total	
		as NH_3	as N_2O_5	as NH_3	as N_2O_5	Total	as NH_3	as N_2O_5
	inches			lb.	lb.	lb.		
September ..	2·10	0·518	0·202	0 246	0·096	0·342	71·9	28·1
October...........	3·23	0·327	0·155	0·239	0·113	0·352	67·9	32·1
November.........	2·83	0·386	0·164	0·247	0·105	0·352	70·2	29·8
December...... ..	2·51	0·384	0·176	0·218	0·100	0·318	68·6	31·4
January	1·99	0·402	0·162	0·181	0·073	0·254	71·3	28·7
February	1·79	0·398	0·200	0·161	0·081	0·242	66·5	33·5
March	1·97	0·420	0·215	0·187	0·096	0·283	66·1	33·9
April	1·57	0·540	0·222	0·192	0·079	0·271	70·8	29·2
May	2·00	0·504	0·203	0·228	0·092	0·320	71·3	28·7
June	1·79	0·543	0·190	0·220	0·077	0·297	74·1	25·9
July	2·63	0·482	0·178	0·287	0·106	0·393	73·0	27·0
August	2·84	0·476	0·171	0·306	0·110	0·416	73·6	26·4
Sept.—Dec.	10·67	0·394	0·171	0·950	0·414	1·364	69·6	30·4
Jan.—April	7·32	0·435	0·199	0·721	0·329	1·050	68·7	31·3
May—August ...	9·26	0·497	0·184	1·041	0·385	1·426	73·0	27·0
April—Sept.......	12·93	0·506	0·191	1·479	0·560	2·039	72·5	27·5
Oct.—March ...	14·32	0·381	0·175	1·233	0·568	1·801	68·5	31·5
Whole year	27·25	0·440	0·183	2·712	1·128	3·840	70·6	29·4

Of greater interest is the comparison of the summer with the winter rain. The rainfall itself of the two seasons does not differ

materially in quantity, although the winter months show a slight excess over the summer. Reference to Table 2 will show that whilst in the winter the total nitrogen amounts to 1·80 lbs. per acre, the summer rain contains 2·04 lbs., the excess being entirely due to an increased production of ammonia, since the nitric nitrogen remains constant. Of the total nitrogen the summer rain contains 72·5 per cent. in the form of ammonia and 27·5 per cent. in the form of nitrates (and nitrites); the winter rain contains 68·5 per cent. and 31·5 per cent. respectively. In other words, to 1 part of nitric nitrogen there are 2·55 parts of ammoniacal nitrogen in the summer, and only 2·15 parts in the winter months.

The influence of the amount of the rainfall on the composition of the rain is illustrated by the results given in Table 3, which shows the average amounts of nitrogen in the two forms in monthly samples of rain below 1 inch, and above 4 inches respectively during the last thirteen years. It happens that in both cases there were exactly the same number of samples (eighteen).

TABLE 3.

NITROGEN AS AMMONIA AND NITRIC ACID IN MONTHLY RAINFALLS.

	Rainfall below 1 inch			Rainfall above 4 inches		
	Rainfall	N. per million		Rainfall	N. per million	
		as Ammonia	as Nitrates		as Ammonia	as Nitrates
	inches			inches		
Min.	0·09	6·236	2·161	4·03	0·314	0·140
Max ..	0·96	0·686	0 285	8·08	0·224	0·090
Mean ...	0·65	0·965	0·442	4·92	0·278	0·124

As was to be expected from the relatively greater variations in the amounts of rainfall below 1 inch, the amounts of nitrogen also differ widely; the average amount of nitrogen per million in the low rainfall is, however, more than twice as high as in the higher rainfall.

Comparing the amount of total nitrogen in the Rothamsted rain with the amounts found, during the past forty years, in various parts

of the world (Table 4), the majority of the results are a good deal higher than those just described. In a few cases, notably Paris and Copenhagen, this may no doubt be attributed to the rain having been collected in, or near large towns. It was to be hoped that the considerable number of results now brought together would enable some kind of grouping to be made; that, for instance, the total nitrogen would show, at any rate in extreme cases, some relation to the rainfall, or would be influenced by proximity to, or distance from, the sea. It is evident, however, that whilst the total nitrogen may vary enormously under apparently quite similar climatic conditions, differences of climate are not necessarily coincident with great variation in the composition of the rain. The rain, for instance, collected at Manhattan, which is about 700 miles from the Gulf of Mexico and more than 1,100 miles from the Pacific, closely resembles the Rothamsted rain. Then again, the 102 inches of rain which fall in British Guiana do not supply to the soil more, but rather less, nitrogen than the 27 inches at Rothamsted.

It will, however, be convenient to consider separately the rain falling in temperate and in tropical countries.

In non-tropical rain the relation of ammoniacal to nitric nitrogen varies less, perhaps, than might be expected from the differences in the amounts of total nitrogen, and the average of all the results recorded in the table (p. 286) is very similar to that found at Rothamsted. With the one exception of New Zealand, the ammonia is greatly in excess of the nitric acid. In the rain of Lincoln, New Zealand, the relation is reversed, the nitric nitrogen being in excess, as in the case of some tropical rains This resemblance is, however, only partial, since the relation of ammonia nitrogen to nitric nitrogen in New Zealand rain is not due to a high amount of nitrates, but to an unusually small amount of ammonia. This is possibly due to the prevalence of sea-winds, as it has been pointed out by Anderlind (2) that the results obtained by Merino (79) in the north-west of Spain show less ammonia when the wind is from the sea than during an overland wind. Heinrich obtained similar indications at Rostock (53). On the other hand Schloesing believes that the sea is the chief source of the ammonia present in the air.

Exceptionally high relations of ammonia to nitric acid occur in the case of Ploty (122) and Pretoria (113); whilst the rain collected at Tokio shows a decidedly low proportion of ammonia to nitric acid. The results obtained at the ten different places (excluding New Zealand) at

TABLE 4.

Nitrogen as Ammonia and Nitric Acid in Rain.

	Date	Rainfall	Nitrogen: Per million, as NH_3	Nitrogen: Per million, as N_2O_5	Nitrogen: Per acre per annum, as NH_3	Nitrogen: Per acre per annum, as N_2O_5	Nitrogen: Per acre per annum, Total	Nitrogen: % of Total, as NH_3
		inches			lb.	lb.	lb.	
Rothamsted	1888-9, 1900-1	27·25	0·440	0·183	2·71	1·13	3·84	70·6
Copenhagen (114)	1880–85	21·95	1·97	0·473	9·27	2·21	11·48	80·8
Gembloux (93)	1889–91	27·23	1·143	0·345	7·07	2·14	9·21	76·8
Montsouris (67)	1876–1900	21·52	2·13	0·66	10·37	3·22	13·59	76·3
Mettray (66)	1877	29·90	0·409	—	2·77	—	—	—
Dahme (39)	1865	17·09	1·42	0·30	5·50	1·16	6·66	82·6
Ida-Marienhütte (25)	1865–70	22·65	—	—	—	—	9·92	—
Insterburg (39)	1864–6	25·67	0·65	0·38	3·90	2·25	6·15	63·1
Kuschen (39)	1864–6	14·78	0·48	0·16	1·63	0·55	2·18	75·0
Proskau (39)	1864–5	17·81	3·21	1·73	12·94	6·97	19·91	65·0
Regenwalde (39)	1864–7	22·72	2·08	0·62	10·69	3·28	13·97	77·0
Rostock (53)	1880–1	33·27	0·892	—	6·73	—	—	—
Florence (11)	1869–75	38·31	1·004	0·57	8·70	3·09	11·79	73·8
Vallombrosa (11)	1872–5	59·89	0·617	0·253	8·36	3·46	11·82	70·7
Scandicci (90)	1888–90	29·18	0·614	0·266	4·06	1·76	5·82	69·8
Catania (10)	1888–9	18·36	0·327	0·161	1·36	0·67	2·03	66·9
St Michele, Tirol (69)	1885–6	43·93	1·188	0·579	11·83	5·76	17·59	67·3
Libwerd, Bohemia	1877–8	24·41	1·3	0·61	7·18	3·37	10·55	68·1
Pečeк, ,,	1883-4 to 85-6	19·34	1·26	0·50	5·53	2·19	7·72	71·6
Ploty (122)	1900–3	17·49	0·854	0·061	3·38	0·24	3·62	93·3
Pretoria (113)	1904*	—	0·68	0·12	—	—	—	85·1
Tokio (59)	1883–4	52·67	—	0·093	—	1·11	2·88	61·6
,, ,,	1885	62·28	0·126	—	1·77	—		
New Zealand (51)	1884–8	29·70	0·076	0·169	0·50	1·13	1·63	30·7
Kansas (42)	1887–9	29·41	0·393	0·154	2·62	1·03	3·64	71·8
Mississippi (112)	1894–5	44·11	0·235	0·074	2·35	0·74	3·09	76·0

Tropical Rain.

	Date	Rainfall	as NH_3 (per million)	as N_2O_5 (per million)	as NH_3 (lb.)	as N_2O_5 (lb.)	Total (lb.)	% as NH_3
Calcutta	1891	46·01	0·172	0·115	1·79	1·20	2·99	59·7
Madras	1888–93	39·21	—	—	—	—	1·91	—
Ceylon (4)	1898–9	82·13	0·196	0·069	3·65	1·28	4·93	72·0
East Java (75)	1891	(47)	0·11	0·06	1·13	0·71	1·84	61·5
Mauritius (21)	1895	(70)	0·43	0·40	6·81	6·34	13·15	51·8
Réunion (88)	1886–7	(40)	—	0·69	—	6·24	—	—
Barbados (5)	1885–97	63·95	0·084	0·268	1·22	3·88	5·10	23·9
Venezuela (71 and 88)	1883–5	(40)	1·55	0·58	14·03	5·20	19·23	72·8
British Guiana† (52)	1890-1900	102·41	0·055	0·078	1·17	1·82	2·99	39·1
Campinas (30)	1890	—	0·99	—	—	—	—	—

* Feb. to June only. † In part unpublished. Communicated by Prof. J. B. Harrison.

which analyses have been continued for at least four years, give an average of 73·5 of nitrogen as ammonia to 26·5 nitric nitrogen.

As regards the tropics, the rain collected in British Guiana and Barbados contains a large excess of nitric over ammoniacal nitrogen, attributed by Harrison (52) to the prevalence of violent thunderstorms. In Mauritius, however, there is a slight excess of nitrogen in the form of ammonia; whilst the rain collected at Caracas, Venezuela, at Calcutta, and at Colombo contains a more or less considerable excess of ammoniacal nitrogen in relation to nitric nitrogen.

The only explanation of these differences seems to be the one offered in the case of New Zealand rain, but this leaves quite unaccounted for the discrepancies shown in the rain of Java and Mauritius and again in that of British Guiana and Venezuela.

The one conclusion which may safely be drawn is that tropical rain does not supply to the soil an essentially greater amount of nitrogen than the rain of temperate climates. The average for the seven tropical places in which both forms of nitrogen have been determined is 7·2 lbs. of nitrogen per acre per annum. And this includes the exceptional amounts found at Caracas and in Mauritius. When these abnormal results are omitted the average total nitrogen for tropical countries is only 3·58 lbs. per acre, with a high average rainfall of 68·3 inches.

NITROGEN AS NITROUS ACID IN RAIN.

The nitrogen in the form of nitrites has not been separately determined in the rain at Rothamsted, being included along with the nitrates, by the reduction method employed; and very few determinations seem to have been made elsewhere. Such results, however, as are available (Table 5) indicate that the amounts of nitrogen present in this form are usually insignificant.

The results of qualitative experiments made by Failyer and Willard with rain collected at Manhattan (42) showed that from December to March only 28 per cent. of the samples contained nitrous nitrogen, whilst from June to September 89 per cent. of the samples gave positive results. There is, however, no evidence to show whether the conditions of the summer months are favourable to the production or merely to the conservation of nitrites.

With regard to the amount of organic nitrogen in the rain-water, the only available analyses relating to Rothamsted are those of

Frankland who found from 0 03 to 0·66 per million in 69 samples. The average amount (0·19 per million) equalled rather more than one-third of the nitrogen present in the forms of ammonia and nitric acid (0 51 per million) The total nitrogen in the Rothamsted rain is, therefore, 3 84 + 1·35 lb, or about 5·2 lb. per acre per annum.

In rain-water collected in New Zealand, Gray found 0 45 lb. of albuminoid nitrogen per acre per annum

TABLE 5

NITROGEN AS NITROUS AND NITRIC ACIDS IN RAIN AND SNOW

	Rainfall	Nitrogen							
		Per million						Per acre	
		as Nitrites			as Nitrates			as Nitrites	as Nitrates
		Min	Max	Mean	Min	Max	Mean		
	inches							lb	lb
St Chamas (31)	(20)	0 0	0 316	0 133	0 001	0 716	0 162	(0 60)	(0 73)
,, (snow)	—	—	—	0 250	—	–	—	—	—
Langres (31) ,,	—	—	—	0 270	—	—	0 881	—	—
Scandicci (90)	27 28	0 0	0 0168	0 0045	0 033	0 729	0 255	0 028	1 687
Catania (10)	18 36	0 0001	0 0027	0 0006	0 035	0 244	0 161	0 003	0 671
Ploty (122)	17 49	0 0	0 025	0 011	0 002	0 178	0 050	0 013	0 197

In addition to the nitrogen brought to the soil by rain, Schloesing (104) has shown that soils may absorb as much as 47 kilos. of nitrogen per hectare per annum directly from the air He found that the character of the soil has no great influence on the absorption, but that the presence of moisture acts favourably owing to the increased nitrification of the ammonia absorbed, and the resulting reduction of the tension of the ammonia in the soil Employing 20 per cent hydrochloric acid as the absorbent, Heinrich (53) found that the ammonia thus fixed amounted to 30·6 kilos per hectare, but he considers that the absorption would probably be less over a large surface, and that the calculation per hectare from a small experiment is not altogether admissible. Müller (84) and Kellner (59), who both employed dilute sulphuric acid, obtained results indicating an absorption of only 12 and 13 kilos respectively of nitrogen per hectare per annum. As these amounts include a certain

quantity of ammonia—perhaps most of it—originally derived from the soil, some of which would, under ordinary conditions, be brought down by the rain, the actual gain due to direct absorption must be less than that indicated by experiments such as those referred to.

CHLORINE AND SULPHURIC ACID.

As already stated the chlorine in the monthly samples of rain has been determined since 1877–8, that is to say for 28 years. The annual amounts of chlorine per acre show great variations, which are to a great extent independent of the total yearly rainfall.

	Date	Rainfall	Chlorine	
			Per million	Per acre
		inches		lb.
um rainfall ..	1897–8	19 51	3·74	16·51
um ,, . .	1878–9	41·05	1·69	15·73
um chlorine ...	1889–90	27·43	1·66	10·32
um ,, ..	1896–7	37·24	2·51	21·19

The maximum and minimum annual rainfalls show, therefore, no very material difference in the amounts of chlorine per acre (both are somewhat in excess of the average), and results may be obtained, quite independently of the total rainfall, which differ by 100 per cent., and are evidently mainly due, on the one hand to a deficiency, and on the other to an excess of rain during the winter months, the rainfall of which, as will presently be shown, contains more than twice as much chlorine per million as that of the summer months.

The amount of chlorine per million varies with considerable regularity from month to month. The lowest amount occurs in July, after which there is a rise until January, when the highest amount is reached. In February there is a drop, followed by a rise in March and then by a fall until July. The amounts per acre show similar variations but with somewhat less regularity.

TABLE 6.

Average Amount of Chlorine in Rothamsted Rain.

1877–8 to 1900–1901	Rainfall (average 24 years) Inches		Chlorine Per million		Chlorine Per acre (lb.)	
September	2·46		1·62		0·90	
October	3·24	11·22	2·46	2·61	1·80	6·41
November	3·03		2·71		1·86	
December	2·50		3·27		1·85	
January	2·06		3·80		1·77	
February	2·03	7·79	3·05	3·16	1·40	5·57
March	1·79		3·56		1·44	
April	1·91		2·22		0·96	
May	2·16		1·76		0·86	
June	2·22	9·79	1·29	1·31	0·65	2·89
July	2·59		1·06		0·62	
August	2·79		1·20		0·76	
Summer (April—September)	14·13		1·49		4·75	
Winter (October—March)	14·65		3·05		10·12	
Whole year	28·78		2·28		14·87	

With regard to the relation between the quantity of the monthly rainfall and the amount of chlorine, the results (see Table 7) show a regular decrease in the chlorine as the rainfall increases, although not in the

TABLE 7.

Average Amounts of Chlorine in Monthly Rainfalls grouped according to the Amount of the Fall.

	Whole Year: Average Rainfall	Whole Year: Chlorine Per million	Whole Year: Chlorine Per acre	Winter: Average Rainfall	Winter: Chlorine Per million	Winter: Chlorine Per acre	Summer: Average Rainfall	Summer: Chlorine Per million	Summer: Chlorine Per acre
	inches		lb.	inches		lb.	inches		lb.
Below 1 in.	0·72	4·11	0·67	0·74	4·95	0·83	0·67	3·23	0·49
1–2 inches	1·43	3·06	0·99	1·46	3·93	1·30	1·41	2·19	0·70
2–3 inches	2·51	2·34	1·33	2·52	3·28	1·87	2·46	1·53	0·85
3–4 inches	3·52	2·24	1·78	3·51	2·76	2·19	3·53	1·41	1·13
Above 4 in.	4·99	1·59	1·80	4·89	2·44	2·70	5·08	0·86	0·99

same proportion, the rate of decrease in the chlorine being much less than the rate of increase in the rain. In this respect the summer and winter rains show great difference. In the summer the monthly rainfalls of 4 inches or more (average 5·08 inches) contain about a quarter as much chlorine per million as is found in the rainfalls of less than 1 inch (average 0·67 inch). With corresponding winter rainfalls the higher amounts of rain contain half as much chlorine as the lower.

No recent determinations of sulphuric acid have been made in the rain at Rothamsted. In the following table is a summary of the results obtained in 1881–7, with the chlorine results, for the same period, for comparison.

TABLE 8.

SULPHURIC ACID AND CHLORINE IN ROTHAMSTED RAIN.

April 1881 to March 1887	Rainfall	Per million		Per acre		SO_3 to 1 Cl
		Cl	SO_3	Cl	SO_3	
	inches			lb.	lb.	
April to September ...	13·90	1·31	2·77	4·11	8·71	2·12
October to March	16·05	2·89	2·39	10·51	8·70	0·83
Whole year	29·95	2·16	2·57	14·62	17·41	1·19

The similarity of the amounts of sulphuric acid in the summer and winter rain is very striking, especially in view of the great variation in the chlorine results. The slightly higher results obtained in the summer as compared with the winter accord with observations made by Russell in London, and support the view that the sulphuric acid is to a great extent an oxidised product of the decomposition of organic matters. Very little of it can be derived from the sea, since the relation of sulphuric acid to chlorine in sea-water is only 11 : 100; and Russell found that rain-water from Dartmoor collected during a strong sea-wind contained only a trace of sulphuric acid.

Compared with London rain the amount of sulphuric acid found at Rothamsted is small; but it is somewhat in excess of the amount found in New Zealand. Sestini found 5·02 per million, equivalent to 20·89 lb. per acre, in the rain collected at Catania.

TABLE 9.

CHLORINE AND SULPHURIC ACID IN RAIN.

	Date	Rainfall	Per million				Per acre		SO_3 to 1 Cl
			Chlorine			Sul-phuric acid	Chlorine	Sul-phuric acid	
			Min.	Max.	Mean				
		inches					lb.	lb.	
Rothamsted	1877–8 / 1900–1	28·78	0·40	20·10	2·28	2·57*	14·87	17·41*	1·19
Cirencester (60).........	1874–1900	30·61	1·15	10·38	3·17	—	21·90	—	—
Scandicci (91)	1889–91	27·67	0·17	31·95	5·63	—	35·35	—	—
Perugia (14)	1886–7	33·96	1·38	40·28	3·15	—	24·22	—	—
Catania (10)	1888–9	18·36	1·47	7·36	5·48	5·02	22·79	20·89	0·92
La Guardia (79)	1892–3	56·42	7·1	71·9	31·2	—	399·5	—	—
New Zealand (51).. ...	1884–8	29·70	2·6	36·4	8·83	2·22	59·44	14·94	0·25
Barbados (5)	1885–97	63·95	3·55	33 97	8·14	—	127·8	—	—
British Guiana (52) ...	1890–1900	102·41	(1·68)	(17·68)	5·04	—	116 88	—	—
Ceylon (4)	1898–9	82·13	—	—	9·72	—	180·63	—	—
Calcutta	1894	46·01	1·82	5·44	3·16	—	32·87	—	—
Madras	1888–93	39·21	—	—	4·08	—	36·27	—	—

* 1881–87.

All the very high chlorine results recorded in Table 9 are to be accounted for by proximity to the sea. In this connexion it may be mentioned that Frankland found as much as 218 parts of chlorine per million in rain collected at Land's End, at a height of about 100 feet above the sea.

It has been pointed out by Kinch (60) that the quantity of chlorine brought down by the rain at Rothamsted and at Cirencester is sufficient for the requirements of most crops. The same may be said as regards the sulphuric acid in the rain at Rothamsted.

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APPENDIX—TABLE I.

SUMMARY OF METEOROLOGICAL OBSERVATIONS AT ROTHAMSTED.

	Rainfall, Average 53 years 1852–1905		Bright sunshine, Average 15 years 1890–1905		Temperature, Average 27 years 1878–1905		
	Total	Days with 0·01 inch	Total	Per cent.	Min.	Max.	Mean
	inches		hours		deg. F.	deg. F.	deg. F.
September............	2·49	13	160·5	43	47·5	64·1	55·8
October	3·18	18	107·0	33	41·1	54·9	48·0
November	2·62	16	58·8	23	36·7	48·3	42·5
December	2·33	16	41·8	18	32·4	42·9	37·7
January...	2·36	16	51·6	21	31·4	41·7	36·5
February	1·80	13	72·8	27	32·5	43·9	38·2
March	1·84	13	117·5	32	33·5	48·3	40·9
April	1·86	13	160·1	39	37·0	54·2	45·6
May	2·19	13	195·2	40	42·1	60·2	51·1
June	2·38	12	196·3	40	48·3	66·4	57·4
July	2·59	13	217·4	44	51·8	70·0	60·9
August	2·67	14	199·0	44	51·1	68·4	59·8
Year............	28·31	170	1578·0	34	40·5	55·3	47·9

APPENDIX—TABLE II.

Rainfall at Rothamsted.

	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.	Year
	inches	inches	inches	inches	inches	inches	inches	inches	inches	inches	inches	inches	inches
1852–3	—	—	—	—	—	—	2·36	3·00	1·68	3·40	4·48	2·98	—
1853–4	2·01	3·66	2·05	0·41	2·03	0·95	0·51	0·50	4·38	0·76	1·05	2·82	21·13
1854–5	0·78	2·29	1·53	1·76	0·60	0·99	2·36	0·41	2·32	1·65	6·96	2·63	24·28
1855–6	1·55	5·50	2·47	1·72	2·78	1·35	1·00	2·61	4·71	1·91	1 48	2·65	29·73
1856–7	2 19	2·87	1·42	2·24	3·71	0·57	1·48	2·16	1·11	2·22	1·61	3·08	24·66
1877–8	1·53	1·95	5·16	2·28	1·75	1·80	0·98	4·09	4 97	2·51	0 65	4·98	32 65
1878–9	1·46	2·99	4·55	1·60	2·85	3·80	1·18	2·79	3·48	5·55	4·24	6·56	41 05
1879–80	3·13	0·82	0·81	0·82	0·55	2·90	1·13	2 16	0·74	1·97	5·26	1·07	21·36
1880–1	5 86	5·94	2·92	3·47	1·14	3·70	2·15	1·00	1·38	1·63	1·76	5·82	36·77
1881–2	2·17	3 05	3·47	4·38	1·57	2·02	1·57	3·92	2·07	3·93	2·09	2·07	32·31
1882–3	2·29	6·52	3·44	3·28	3·30	4·34	0·89	1·48	1·89	2·23	4·21	0·84	34·71
1883–4	3·99	2·49	3·52	1·16	2·56	1·42	1·66	1·79	0·64	2·50	2·44	1·60	25·77
1884–5	2·18	1·70	2·05	3·06	2·99	2·85	1·46	2·88	2·88	2·76	0·38	1·59	26·78
1885–6	4·39	4·82	3·77	1·33	3·44	0·61	1·59	1·96	4·24	1·23	2 42	1·22	31·02
1886–7	1·51	3·94	2·77	4·21	2·39	0·95	1·76	1·19	2·35	0·71	0·79	1·04	23·61
1887–8	3·11	1·69	3·41	1·66	0·94	1 03	3·13	2·14	1·28	4·87	3·86	3·38	30·50
1888–9	1·03	1·09	4·45	1·69	1·29	1·95	1·89	2·47	5·00	1·38	5·67	2·18	30·09
1889–90	2·44	3·62	1·21	1·46	2·94	0·82	2·78	1·31	1 38	2·40	4·56	2·51	27·43
1890–1	1·20	1·57	2·76	0·56	2·25	0·09	1·76	1·50	3·46	1·89	2·34	4·03	23·41
1891–2	1·39	6·76	2·25	4·13	1·01	1·48	1·22	0·79	1·40	2 56	3·00	3·69	29·68
1892–3	2·46	3·99	2·06	1·63	2·05	3·62	0·42	0·25	1·22	1·00	3·00	2·38	24·08
1893–4	1·14	4·46	2·92	2·63	2·38	1·96	2·19	1·71	2·07	2·01	2·40	3·68	29·55
1894–5	2·22	3·45	4·98	2·18	2·23	0·19	1·91	1·47	0·69	0·45	5·12	4·05	28·94
1895–6	1·06	2·69	4·96	2·34	1·12	0·59	3·75	0 95	0·48	2 25	1·27	2·91	24·37
1896–7	8·08	4·13	1·39	4 42	2·03	2·92	4·20	1·91	1·72	2·73	0·47	3·24	37·24
1897–8	2·44	0·96	1·05	3 50	0·80	1·10	1·06	1·44	2·89	1·61	1·45	1·21	19·51
1898–9	0·60	2·89	2·44	3·01	2·96	2 44	0·87	2·73	2·81	1·58	1·28	1·09	24·70
1899–1900	2·46	3·75	3·76	1·41	3·67	4·91	0·96	1·33	1·08	2·63	1·13	3·93	31·02
1900–1	0·84	2·60	2·60	3·65	1·18	1·26	2·57	2·51	1·81	0·84	2·44	2·00	24·30
1901–2	1·35	2·03	1·05	4·13	0·83	1·25	1·49	0·83	2·20	3·33	1 24	3 53	23·26
1902–3	1·05	1·88	1·95	1·39	2·55	1·06	3·47	1 53	2·22	6·12	4·08	3·96	31·26
1903–4	2·75	6·32	2·21	2·42	3·50	3·45	1·58	1·25	2·15	0·81	2 92	2 15	31·51
1904–5	1·59	1·37	1·67	2·48	1·34	0·95	3·57	2·22	1·13	4·05	1·47	3·46	25·30

APPENDIX—TABLE III.

NITROGEN AS AMMONIA IN RAIN-WATER COLLECTED AT ROTHAMSTED IN PARTS PER MILLION.

	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.	Year
1852–3	—	—	—	—	—	—	1·19	0·67	1·10	1·05	0·77	0·69	—
1853–4	0·61	0·57	0·66	1·33	0·64	0·78	0·78	0 80	0·37	—	—	—	—
1854–5	—	—	—	—	1·08	1 22	1·01	1·45	0·94	1·59	0·72	0·94	—
1855–6	1·12	0·72	0·64	0·79	0·93	1·60	1·09	1·72	1·49	1·33	1·00	0·82	1·08
1856–7	1·42	0·71	0·94	0·94	—	—	—	—	—	—	—	—	—
1877–8	—	0·350	—	—	—	—	0·357	0·466	—	—	-	—	—
1878–9	0·576	—	—	—	0·219	0·298	0·638	0·617	0 470	0·384	- -	—	—
1879–80	0·412	0·988	—	1·038	0·495	0·371	0·371	0·881	1·276	0·508	0·309	—	—
1880–1	0 160	0·165	--	0·162	0·659	0·467	—	0·604	0·631	0 412	0·618	0·178	—
1881–2	0·350	0·214	0·237	0·196	0·422	0·227	0·313	0·319	0·535	0·445	0·503	0·453	0·334
1882–3	0·401	0·254	0·137	0·360	0·213	0·199	0 856	0·576	0·412	0·391	0·432	0·725	0·339
1883–4	0·362	0·280	0·190	0·824	0·268	0·453	0·412	0·617	0·617	0·576	0·350	0·463	0·400
1884–5	0·275	0·412	0·361	0·230	0·319	0·213	0·453	0 535	0·350	0·350	1·071	0 638	0·370
1885–6	0·178	0·247	0 275	0·577	—	—	—	—	—	—	—	—	—
1887–8	—	—	—	0·337	—	0 538	0·315	0·600	0·256	0·500	0·388	0·288	—
1888–9	1·025	0 525	0 313	0·500	0·575	0·238	0·400	0·575	0·300	0·378	0·350	0·538	0·412
1889–90	0·625	0·338	0·625	0·413	0·363	0·625	0·288	0·600	0·625	0·463	0·363	0·425	0·445
1890–1	0·775	0·475	0·225	1·300	0·450	0 250	0 550	0·625	0·350	0·719	0·417	0·313	0·483
1891–2	0·594	0·300	0·495	0·291	0·562	0·656	1·000	0·800	0·700	0·425	0·700	0·300	0·466
1892–3	0·625	0·250	0·675	0·225	0·500	0·350	1·625		0·950	1·000	0·500	0 650	0·535
1893–4	0·550	0·200	0·233	0·250	0·350	0·375	0·213	0·625	0·458	0·625	0·400	0·583	0·381
1894–5	0·625	0·300	0·150	0·325	0·300	0·958	0·500	0·575	1·167	1·437	0·225	0·357	0·364
1895–6	0·700	0·325	0·287	0·350	0·650	0·950	0·350		0·800	0·675	0·900	0·675	0·484
1896–7	0·225	0·250	0·350	0·275	0·400	0·375	0·233	0·383	0·625	0·525	1 375	0·525	0·350
1897–8	0·400	0·688	0·813	0·225	0·781	0·525	0·475	0·600	0·640	0·529	0·600	0·550	0·516
1898–9	1·350	0·575	0·475	0·288	0·225	0·238	0·950	0·525	0·350	0·313	0·475	0·781	0·443
1899–1900	0·500	0·275	0·525	0·900	0·263	0·250	0 550	0·700	0·650	0·333	0·950	0·400	0·431
1900–1	0·800	0·288	0·625	0·675	0·575	0·400	0 275	0·263	0·375	0·575	0·750	0·525	0·498
1901–2	0·625	0·625	0·550	0·225	0·383	0·867	0·475	1·500	0·625	0·550	0·575	0·675	0·571
1902–3	1·500	0·525	0·675	0·475	0·400	0 500	0·312	0·450	0·541	0·417	0·275	0·313	0·447
1903–4	0·500	0·263	0·325	0·600	0·375	0·300	0·575	0·625	0·625	0·750	0·417	0·600	0·424
1904–5	0·719	0·475	0·313	0·400	0·263	0·600	0·250	0·750	0·900	0·350	0·821	0·350	0·460

APPENDIX—TABLE IV.

Nitrogen as Nitrates in Rain-Water collected at Rothamsted in parts per Million.

	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug	Year
1854–5	—	—	—	—	0·06	0·16	0·08	0·13	0·13	0·30	0·06	0·22	—
1855–6	0·08	0·13	0·07	0·06	0·09	0 07	0·13	0·07	0 10	0·17	0·13	0·15	0·10
1856–7	0·13	0·12	0·16	0·15	—	—	—	—	—	—	—	—	—
1886–7	0·270	0·089	0·064	0·048	0·172	—	0·247	0·106	0·162	0·284	0·204	0·385	0·138
1887–8	0·093	0·090	0·093	0·066	0·198	0·229	0·095	0·145	0·109	0·167	0·104	0·090	0·116
1888–9	0·253	0·173	0·096	0·155	0·190	0·095	0·136	0·230	0·100	0·184	0·120	0·096	0·134
1889–90	0·150	0·083	0·180	0·127	0·097	0·220	0·093	0·220	0·185	0·104	0·083	0·123	0·119
1890–1	0·330	0·213	0·120	0·773	0·120	2·160	0·200	0·200	0·130	0·246	0·200	0·140	0·195
1891–2	0·240	0·192	0·213	0·080	0·213	0·240	0·306	0·300	0·213	0·160	0·200	0·147	0·185
1892–3	0·187	0·120	0·420	0·098	0·288	0·147	0·640		0·347	0·340	0·173	0·187	0·217
1893–4	0·160	0·088	0·090	0·090	0·114	0·150	0·093	0·240	0·173	0·147	0·160	0·160	0·131
1894–5	0·267	0·128	0 072	0·140	0·088	0·667	0·420	0·260	0·500	0·380	0·100	0·120	0·161
1895–6	0·320	0·200	0·142	0·222	0·260	0·420	0·170		0·540	0·220	0·240	0·267	0·216
1896–7	0·090	0·080	0·170	0·200	0·130	0·290	0 210	0·147	0·187	0·178	0·460	0 150	0·160
1897-8	0·166	0·286	0 293	0·120	0·300	0·173	0·333	0·320	0·270	0·200	0·293	0·320	0·234
1898–9	0·720	0·240	0·251	0·120	0·130	0·150	0·427	0·227	0·180	0·285	0·267	0·460	0·228
1899–1900	0·227	0 190	0·200	0·620	0·160	0·150	0·290	0 213	0 240	0·093	0·360	0·128	0·200
1900–1	0·580	0·200	0·187	0·220	0·293	0·320	0·187	0·160	0·280	0·320	0·347	0·267	0·250
1901–2	0·267	0·251	0·270	0·200	0·160	0·336	0·176	0·320	0·206	0·500	0·274	0·200	0·267
1902–3	0·560	0·272	0·304	0·375	0·225	0·300	0·125	0·250	0·180	0·168	0·116	0·135	0·203
1903–4	0·183	0·133	0·263	0·288	0·213	0·133	0·213	0·313	0·450	0·317	0·175	0·275	0·214
1904–5	0·325	0·325	0·213	0·142	0·133	0·250	0·125	0·225	0·375	0·125	0·313	0·163	0·197

APPENDIX—TABLE V.

CHLORINE IN RAIN-WATER COLLECTED AT ROTHAMSTED IN PARTS PER MILLION.

	Sept.	Oct.	Nov.	Dec.	Jan	Feb.	Mar.	April	May	June	July	Aug.	Year
1876-7	—	—	—	—	—	—	—	—	—	1·95	0·24	0·95	—
1877-8	1·73	3·40	1·97	1·96	2·91	0·50	4·00	0·55	0·91	1·48	4·31	1·16	1·62
1878-9	2·28	2·58	1·83	3·00	3·04	1·83	5·80	1·67	1·40	0·80	0·80	0 85	1·69
1879-80	1·05	2·65	9·38	5·75	3·20	3·20	2·90	1·73	3·43	2·47	0·64	1·30	2 25
1880-1	0·97	3·00	2·95	1·70	10·00	3·45	1·95	3·20	2·38	1·63	0·67	0·53	2·17
1881-2	0·75	4·20	2·70	1·80	1·70	2·50	3·75	2·60	1·60	0·80	1·60	1·68	2 13
1882-3	1·15	2·28	4·30	1·60	3·00	2·25	8·85	1·60	1·40	1·12	0·73	2·00	2 23
1883-4	1 90	2 50	2·30	8·80	3·60	5·75	1·65	1·65	3·70	0·80	0·62	0·90	2·43
1884-5	0 85	2·25	3·33	3·30	3·42	2·75	2·35	1·45	1·50	0 75	1·45	2·27	2·20
1885-6	1·00	1·90	1·57	3·43	2·58	2 25	3·60	2·77	0·93	0 98	0·50	1·45	1·73
1886-7	2·10	2·95	1·65	4·63	2·28	3·50	3·28	4·75	2·15	2·00	2·90	2·70	2·99
1887-8	2·70	3·35	2·95	2·73	4 90	11·05	3 40	2·20	2·50	0·75	1·33	1·03	2·46
1888-9	2 30	2·15	2·37	3·43	3·05	3·90	2·25	2·55	0·40	2·17	0·77	1·42	1·85
1889-90	1·30	1·83	2·40	2·10	3·05	3·95	1·60	2·93	1·15	1·15	0·43	1·20	1·66
1890-1	1 90	2 00	1·95	8·05	2·50	7·50	3 50	2·50	1·30	1·25	1·45	1·20	1·99
1891-2	2 00	2·71	2·75	2·75	4·08	3·45	4·20	2·60	2·40	1·20	1·00	1·13	2·31
1892-3	1·95	1·75	1·82	1·08	3·20	2·85	4·95		2·15	2·32	1·30	1·25	2·05
1893-4	3·04	1·68	4·44	6·80	4·62	2·95	2·87	2·05	2·50	1·20	1·00	0 50	2 71
1894-5	1·90	2·25	2·10	4·06	4 90	4 02	3 38	1·44	2·80	3·00	1·00	1·20	2·25
1895-6	1·40	2·04	2·80	4·20	3·18	3·86	2·22		4 10	1·89	1·94	1·13	2·42
1896-7	1·25	2·52	3·39	2·28	8·61	1·82	3·48	2·94	2 10	1·55	3 92	1·74	2·51
1897-8	1·70	4 20	4·98	3·81	3·59	4·47	20·10	2·30	2·25	2·04	1·25	1·88	3·74
1898-9	5·63	2·51	2·85	2·78	5·88	4·80	5·33	2·42	2·40	1·50	1·37	2·55	3 24
1899-1900	2·22	1·67	2·75	4·70	2·22	1·88	5·93	3·68	2·25	1·26	2·09	1·28	2·25
1900-1	3·69	2 34	3·83	3·45	7·13	3·96	1·43	2 70	5 03	2·90	1·40	1·43	3·02
1901-2	2·43	4·44	5·49	2·85	3·00	6·38	2 04	3·80	3·08	1·35	1·83	1·53	2·81
1902-3	3·05	3·56	4·58	5·49	4·02	5·48	3·00	3·90	1·74	1·02	0·80	1·68	2·52
1903-4	1·95	2·07	2·42	5·01	3·15	4·65	4·62	3·18	2·45	2·65	0 81	1·77	2·76
1904-5	1·98	2·25	1·92	2·33	3·14	11·60	3·68	3·54	2·90	1·49	0·94	1·50	2·66

THE HYGROSCOPIC CAPACITY OF SOILS.

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THE present communication is intended as a contribution to the study of the capacity of soils to retain moisture in equilibrium with the atmosphere. The experimental material with which it deals consists in part of the analytical data obtained in the investigation of one hundred soils of the county of Dorset, which has been carried out for the County Council, and in part of a series of determinations made for the purpose of elucidating this problem.

All the results refer to fine earth passing through a sieve with round holes 3 mm. in diameter, and the experiments were all made under laboratory conditions, so that no account is taken of the influence of tilth, nor of the stones and gravel with which the fine earth is associated. It is hoped that these drawbacks will be partially removed by a further series of determinations which are contemplated.

The hygroscopic property of soils is due to a variety of causes, which may be roughly grouped under four heads:

1. The proportion and character of the organic material in the soil.
2. The size of the mineral particles, or rather the proportion in which particles of different sizes are present.
3. The chemical and physical nature of the mineral constituents.
4. The temperature, and the humidity of the atmosphere.

It is intended first to deal with the bearing of the analytical data of the Dorset soils on the influence of the first three of these factors, and then to adduce the results of the special experiments showing the hygroscopic capacity of soil particles under varying atmospheric conditions.

INFLUENCE OF ORGANIC MATERIAL.

One of the most potent factors in enabling the soil to retain moisture is known to be the organic material it contains. The relation between the content of organic matter and the content of water is shown in Tables 1 and 2. In these tables the Dorset soils are arranged in four groups according to their loss on ignition, and the maximum, minimum, and mean percentage of moisture is given for each group. The loss on ignition is exclusive of carbon dioxide, but includes combined water.

TABLE 1.

Number of Soils	Loss on Ignition, per cent.			Water in Air-dry, per cent.		
	Maximum	Minimum	Mean	Maximum	Minimum	Mean
24	21·5	10·4	12·9	6·5	2·2	4·6
25	9·7	8·0	8·7	5·9	2·0	3·1
23	7·9	6·0	7·0	4·4	1·2	2·8
28	5·9	2·9	4·9	3·2	·6	1·7

TABLE 2.

Number of Soils	Loss on Ignition, per cent.			Water in Air-dry, per cent		
	Maximum	Minimum	Mean	Maximum	Minimum	Mean
8	21·5	13·3	15·6	6·5	4·5	5·6
44	12·8	7·9	9·7	5·9	2·0	3·4
39	7·8	4·8	6·1	4 4	1·0	2·4
9	4·7	2·9	4·1	1·9	·6	1 3

The hygroscopic capacity of a soil is not of course a simple function of its percentage of organic material. Soils differ much in the proportion that exists between the loss they suffer on ignition and their content of moisture, nor is this difference wholly to be explained by the influence of other factors. But to obtain in the first place a numerical expression for the relation which obtains between these and similar quantities, generally, in spite of many individual irregularities, the coefficient of correlation has been calculated from the analytical data of the Dorset soils. This factor has been much used lately in other branches of science, and seems likely to afford useful information in the present enquiry. The coefficient of correlation is a number which varies in different cases through all values from $+1$ which connotes

complete interdependence of two measurable quantities through fractional values representing degrees of positive correlation down to zero for unconnected quantities, and then through negative fractions to -1 for perfect correlation in an inverse sense[1]. In this paper it will be expressed by such symbols as $R_{100}\left(\frac{\text{moisture}}{\text{loss on ignition}}\right) = {\cdot}83$. This indicates that the coefficient of these quantities calculated from the data of 100 soils has the value given. The second place of decimals is usually given, but is of doubtful significance.

That the hygroscopic power of the organic material is chiefly due to non-nitrogenous constituents is no doubt a general opinion, and seems to be confirmed by the following figures:

$$R_{100}\left(\frac{\text{moisture}}{\text{nitrogen}}\right) = {\cdot}74, \quad R_{100}\left(\frac{\text{nitrogen}}{\text{loss on ignition}}\right) = {\cdot}91.$$

The connexion between moisture and nitrogen is probably only indirect; the correlation between the other pairs of the three quantities is high and is no doubt causal; there would thus of necessity be a correlation between moisture and nitrogen, though they had absolutely no direct connexion as cause and effect.

Fineness of the Soil.

The dependence of the hygroscopic power of the soil on the fineness of its particles is well known. Further on an attempt is made to give this some definite numerical expression. To obtain a factor of correlation from the mechanical analysis of the soils one has to choose a single figure to express the fineness of each soil, and this is a matter of some difficulty. The soil is mechanically divided into six or seven fractions containing particles of various grades varying in diameter from about 2 millimetres down to less than 2μ. An obvious figure to take is the ratio between particles above and below a definite size, or, what comes to the same thing, the percentage of material below a certain limit. Taking this limit at 10μ we get $R_{82}\left(\frac{\text{moisture}}{\text{fine material}}\right) = {\cdot}66$. By raising the limit to 40μ or lowering it to 4μ the coefficient is reduced to ·56 and ·54. If again there is taken as a measure of fineness the percentage under 2μ

[1] Convenient methods for calculating the coefficient of correlation are given on pages 64–72 of "The Measurements of Groups and Series," by my colleague Mr A. L. Bowley, M.A., F.S.S.

(clay) plus fractions of the percentage of the next two coarser grades (·4 [2μ to 4μ] + ·16 [4μ to 10μ]) the coefficient works out to ·53.

Only 82 soils are used for these calculations, namely those containing less than 7 per cent. of calcium carbonate. The figures used as a measure of fineness include the organic as well as the mineral particles except that the humus soluble in aqueous ammonia is removed. In Table 3 the soils are grouped into four sets according to the ratio of coarse material to fine, the line of demarcation being taken at or about 10μ. The moisture is readily seen to vary inversely as the ratio of the coarse particles to the fine.

TABLE 3.

Number of Soils	Ratio of Coarse to Fine Material			Water in Air-dry, per cent.		
	Maximum	Minimum	Mean	Maximum	Minimum	Mean
16	50 : 50	25 : 75	40 : 60	6·5	2·1	4·3
24	65 : 35	48 : 52	60 : 40	6 0	1·5	3 2
26	77 : 23	66 : 34	72 : 28	5·0	1·4	2·6
16	91 : 8	78 : 22	84 : 16	3·0	·6	1·5

NATURE OF THE MINERAL CONSTITUENTS.

The first indication of the chemical and physical nature of the mineral constituents that falls to be considered is the total percentage brought into solution by digestion with hot concentrated hydrochloric acid. It is necessary, however, either to confine attention to soils with only a moderate amount of calcium carbonate, or to subtract this constituent from the total minerals before attempting to calculate a correlation coefficient Of the Dorset soils 18 contain a percentage varying from 70 to 9, whilst the remaining 82 contain from 7 down to 0·3 per cent. of calcium carbonate. The following results have been obtained:

$$R_{82}\left(\frac{\text{moisture}}{\text{total soluble minerals}}\right) = {\cdot}72,\quad R_{100}\left(\frac{\text{moisture}}{\text{soluble minerals} - CaCO_3}\right) = {\cdot}74,$$

$$R_{100}\left(\frac{\text{moisture}}{CaCO_3}\right) = 0 \text{ (nearly)}.$$

The zero value of the last coefficient is not adduced to show that calcium carbonate has no hygroscopic property, but with the close agreement between the two factors for moisture and soluble minerals it fully justifies the method of calculation.

Table 4 gives the 82 soils divided into four groups according to their percentage of soluble minerals, and illustrates the dependence of moisture on this factor. It is seen how the mean water content of each group varies with its mean percentage of mineral constituents soluble in hot concentrated hydrochloric acid. But as in the other tables, the relation is far less manifest in the maxima and minima because here individual differences make themselves evident, and the influence of other factors comes into play.

TABLE 4.

Number of Soils	Soluble Minerals, per cent.			Water in Air-dry, per cent.		
	Maximum	Minimum	Mean	Maximum	Minimum	Mean
16	26·9	18·0	21·3	6·5	3·2	4·7
23	17·6	13·0	15·2	6·0	2·1	3·2
25	12·2	8·2	10·2	6·0	1·0	2·6
18	8·0	1·7	5·7	3·0	·6	1·5

The high correlation between moisture and soluble mineral constituents is rather surprising, especially as it seems to show a greater dependence on this factor than on the fineness of the soil. This may be partly due to the difficulty of expressing the fineness of the soil by a single number suitable for the calculation, and it is certainly partly the result of the physical condition of the finer particles in the laboratory samples, for the clay is unable to exert its full hygroscopic influence.

But even irrespective of comparison with the factor obtained from the results of mechanical analysis, the high figure obtained for the correlation of moisture with soluble minerals deserves consideration. The question arises whether the influence of the soluble minerals is due to their chemical nature being different from that of the insoluble residue, or whether their hygroscopic power and their susceptibility to the attack of hot acid are only indirectly connected as the results of a common cause to be found in their physical condition both as to fineness and in other ways.

For the purpose of elucidating this problem the coefficient of correlation was calculated in the first place for moisture with each of the several constituents dissolved, and the following results were obtained:

$$R_{100}\left(\frac{H_2O}{P_2O_5}\right) = \cdot 25, \quad R_{100}\left(\frac{H_2O}{SO_3}\right) = \cdot 49, \quad R_{100}\left(\frac{H_2O}{K_2O}\right) = \cdot 44,$$

$$R_{100}\left(\frac{H_2O}{Na_2O}\right) = \cdot 24, \quad R_{100}\left(\frac{H_2O}{MgO}\right) = \cdot 36,$$

$$R_{100}\left(\frac{H_2O}{Al_2O_3}\right) = \cdot 58, \quad R_{100}\left(\frac{H_2O}{Fe_2O_3}\right) = \cdot 64.$$

If the high water content of soils with high percentage of minerals soluble in acid is due to the soluble materials being in a fine condition, and therefore both readily attacked by acid on the one hand and with a large surface attraction for moisture on the other hand, we should expect the alumina to give us a good measure of the property, as it is the principal base in soluble silicates, and is little affected by manuring and cropping. The actual figure of ·6 obtained is only a little below ·7, which represents the correlation with total minerals, whilst all the other constituents except iron oxide give lower figures. The phosphorus pentoxide of course is very low, the potash is higher perhaps because the soils generally being rich in this constituent the influence of cropping is less than it would be in other soils. Before drawing conclusions from these figures even tentatively, it should be mentioned that possibly a partial cause for the high correlation between water and soluble minerals may be found in an effect of the organic substance in rendering the minerals soluble.

$$R_{100}\left(\frac{\text{loss on ignition}}{\text{soluble minerals} - CaCO_3}\right) = \cdot 60.$$

Here again, however, it is difficult to be sure of the cause, as the soluble minerals would probably raise the combined water which is included in the loss on ignition.

TABLE 5.

Number of Soils	Iron Oxide, per cent.			Water in Air-dry, per cent.		
	Maximum	Minimum	Mean	Maximum	Minimum	Mean
14	14·7	6·8	9·0	6·0	3·1	4·4
26	6·6	4·6	5·7	6·5	2·0	3·8
47	4·5	2·4	3·4	6·0	1·0	2·5
13	2·2	·4	1·4	2·8	·6	1·9

It remains to consider the high figure obtained for iron oxide. It seems probable that this indicates a definite causal relation between the

presence of iron oxide and the hygroscopic capacity of the soil. The relation is shown in Table 5 similarly to that in other cases.

It would seem a reasonable hypothesis that the mineral constituents of the soil having a notable hygroscopic effect may be divided into three groups, namely:

A. Silicates and silica in fine particles, the silicates not decomposable by hot concentrated hydrochloric acid. This material owes its hygroscopic influence entirely to surface attraction for water.

B. Silicates decomposable by the hot acid used. This material is probably to a large extent in a condition of sufficient fineness to give it considerable power of surface attraction. The base present in largest and most regular quantity is likely to be alumina, the percentage of which dissolved by the acid may therefore be taken as a measure of the amount of this material.

C. Iron oxide and its compounds having a specific attraction for moisture that may perhaps be correlated with the possibility of formation of loosely combined chemical hydrates.

On this hypothesis the influence of groups *A* and *B* would be found in the coefficient obtained from the mechanical analysis results, whilst that of *C* would of course be measured by the factor $R\left(\frac{\text{moisture}}{\text{iron oxide}}\right)$ already given.

But if this hypothesis be correct, the factor obtained for alumina and iron oxide should not differ much from that for total soluble minerals, the other constituents being regarded as negligible. In point of fact

$$R_{100}\left(\frac{H_2O}{Al_2O_3 + Fe_2O_3}\right) = \cdot 71,$$

which agrees well with the other factor ·72 or ·74.

The dependence of the moisture in the soil on the organic material and on the soluble minerals severally suggests that the correlation would be still closer with their sum, and, as the total weight of the fine earth is made up of the four parts—water, loss on ignition, soluble minerals, and insoluble residue—this is the same thing as saying that there will be close correlation in the inverse sense between water and insoluble mineral substance.

$$R_{82}\left(\frac{\text{moisture}}{\text{insoluble minerals}}\right) = -\cdot 9 \text{ or } -\cdot 88$$

(according to the method of calculation).

The relation is clearly shown in Table 6.

TABLE 6.

Number of Soils	Insoluble Minerals, per cent.			Water in Air-dry, per cent.		
	Maximum	Minimum	Mean	Maximum	Minimum	Mean
11	64	56	60	6·5	4·1	5·3
30	76	66	72	5·0	2·0	3·3
31	87	77	82	3·6	1·0	2·2
10	95	88	90	1·9	·6	1·2

COMPOSITION OF THE SOILS.

For the sake of giving a general idea of the character of the soils on which the above results are based, there are given in Table 7 the mean percentages of some of the principal constituents, with in many cases the standard deviation from the mean[1]. Some of these figures are taken from the whole of the 100 soils and some only from the 82 which contain less than 7 per cent. of calcium carbonate, so that the data do not give the exact analysis of even an imaginary soil, but rather serve to indicate the range of values which have been used in the calculations.

TABLE 7.

		per cent.
Water lost at 95° C.	(100)...	3·0 ± 1·3
Organic Substance and Combined Water	,, ...	8·3 ± 3·2
Containing Nitrogen..........................	,, ...	·26 ± ·13
Insoluble Mineral Substance	(82) ...	76·5 ± 9·3
Soluble Mineral Constituents	,, ...	12 6 ± 5·5
Phosphoric acid anhydride	(100) ..	·37 ± ·14
Sulphuric acid anhydride	,, ...	·25 ± ·13
Potash.........	,, ...	·41 ± ·21
Soda...	,, ...	·31 ± ·17
Carbonate of Lime	,, ...	70·0 to ·03
Magnesia	,, ...	·40 ± ·24
Iron Oxide	,, ...	4·5 ± 2·5
Alumina	,, ...	4·5 ± 2·5

EXPERIMENTS WITH SOIL PARTICLES.

The experiments which now come to be described were carried out with a view to determining the relative hygroscopic power of mineral

[1] Standard deviation or deviation of mean square

$$=\left(\frac{\delta_1^2+\delta_2^2+\ldots+\delta_n^2}{n}\right)^{\frac{1}{2}}.$$

soil particles of different sizes, and ascertaining how far this property may be regarded as proportional to the probable area of the surface they offer to the atmosphere.

Seven different soils have been used altogether, and in addition some coarse sand, extracted with strong hydrochloric acid and ignited, was ground down under water to give a kind of artificial soil free from organic matter and soluble mineral constituents. The ground sand and the soils were separated by sifting and elutriation into six fractions, of which the approximate mean diameters were found to be as follows, expressed in thousandths of a millimetre:

I, 300; II, 80; III, 24; IV, 8; V, 3; VI, $1\frac{1}{8}$.

First Series of Experiments.

In the first series of experiments a number of small weighing bottles were prepared, containing respectively a gram each of five different soils and of their six fractions. These were put under a bell-jar, together with a dish which contained during most of the experiments a solution of calcium chloride of which the concentration was determined when the bottles were removed for weighing; at the conclusion of the series the dish was filled with granular calcium chloride in order to obtain the weight of the samples in equilibrium with a dry atmosphere. The water lost at 95° and the loss on ignition were also found, but all results are calculated to the weight of the material dried in this manner in the cold.

In Table 8 the results of this series are given so as to show their bearing on the question of surface action. There were not an adequate number of observations under sensibly equal atmospheric conditions to eliminate accidental variations, and to give one confidence in the results for each soil-fraction separately; the figures are therefore grouped so that under I for example is given the mean gain of moisture of each of the five soil-fractions of this grade, and similarly for II, III, IV, V, VI. So, too, the percentage loss on ignition treated as organic matter is calculated for the mixed material of the five soils.

The gain of weight is given in Table 8 for each of five different atmospheric conditions. In the so-called normal atmosphere, standing over approximately $CaCl_2, 9H_2O$, the soils and fractions had much the same weight as in what is usually called the air-dry condition. The succeeding lines give figures for atmospheres of increasing moistness.

TABLE 8.

Fractions	I	II	III	IV	V	VI
Mean diameter in mikrons	300	80	24	8	3	1⅓
Organic matter per cent.	16·6	5·5	10·5	15·9	20·4	29·6
Moisture absorbed per cent.:						
9. Normal atmosphere	1·02	·43	·84	1·39	1·82	2·16
17. Moist atmosphere	1·80	·79	1·54	2·61	3 68	5 02
22. ,, ,,	2·63	1·21	2·39	3·95	5·69	8·97
37. ,, ,,	2·82	1·30	2·54	4·09	6·32	11·78
74. Very moist atmosphere	3·63	1·68	3·33	5·45	7·83	20·17
Mean of all	2·38	1·08	2·13	3·50	5·07	9·62
Allow for Organic	2·38	·79	1·50	2·27	2·91	4·23
Due to Surface	—	·29	·63	1·23	2·16	5·39
Moisture Multiple	—	—	2·2	2·0	1·8	2·5
Mean of 9, 17, 22	1·82	·81	1·59	2·65	3·73	5·38
Allow for Organic	1·82	·60	1·15	1·74	2·24	3·25
Due to Surface	—	·21	·44	·91	1·49	2·13
Moisture Multiple	—	—	2·1	2·1	1·7	1·5
Surface Multiples: diameter^{-1}	—	—	3·3	3·0	2·7	2·3
Surface Multiples: diameter$^{-\frac{2}{3}}$		—	2·2	2·1	1·9	1·7

A comparison of the gains of fraction I with those of fraction II shows the great power that organic matter has of attracting moisture. In the succeeding fractions the percentage of organic matter rises steadily with diminishing dimensions of the particles, and thus the order of magnitude is always increasing as we pass to the right from II towards VI. But to obtain an expression for surface effect it is necessary to eliminate the influence of the organic matter, and this offers a difficulty. We proceed on the basis of two assumptions. Firstly, we suppose that all the organic material is equally hygroscopic, whatever size its particles be, or whatever other differences there may be between the organic matter of the different fractions. Secondly, it is assumed that the hygroscopic power of fraction I is entirely due to its organic matter. Underneath the figures in the table giving the mean gains of each fraction there are set down the amounts that must be allowed for organic matter on the above assumptions. The difference is the value to be attributed to surface attraction. The ratio of the surface effect of each of the four finer fractions to the next coarser is called the moisture multiple, and is given in the next line. The moisture multiples are given for the mean of the three less moist atmospheres as well as for the

mean of the whole series. Whilst all the figures in the tables show a satisfactory general regularity in their increase, the moisture multiples are somewhat irregular. In other words, whilst the figures show that the moisture gained increases alike with increased organic matter and increased moistness of the atmosphere and diminished dimensions of the particles, they do not give very clear information as to the law which connects the increase of moisture with increased fineness of the particles. It should, however, be observed that the irregularity is chiefly connected with the high water content of the finest particles (VI or so-called clay) in the very moist atmosphere. Apart from this the moisture multiples are approximately inversely proportional to the two-thirds power of the diameter.

At the beginning of the experiments fluctuations of temperature were found to be considerable, and, it was feared, rather rapid; and this was the more serious as some of the fractions were somewhat slow in attaining equilibrium with the atmosphere. To reduce fluctuations a large tin jacket containing water was put over the bell-jar, and by the use of a maximum and minimum thermometer inserted in the water a more exact knowledge of the temperature variations was obtained. The temperature was not kept exactly uniform, but the samples were left under the bell-jar for prolonged periods, and only removed for weighing when the temperature variations had been slight during several days. The water-jacket was used during the latter part of the first series of experiments, and during the whole of the series to be presently described.

SECOND SERIES OF EXPERIMENTS.

The first series of experiments showed considerable irregularities in the individual figures obtained, notwithstanding the general agreement shown in Table 8. Some of these might have been due to temperature fluctuations, but they cannot be altogether accounted for in this manner, and some of the variations in weight seem inexplicable. To reduce the effect of these as much as possible the second series of experiments was extended over a greater number of observations, and more duplicates were used. The standard weights attained in a cold, dry atmosphere were determined eight times, five times over granular calcium chloride, and three times over fused caustic potash, and the results obtained were in most cases in satisfactory agreement. Then the results given in Table 10 as the moisture gains in a particular atmosphere are the means of several determinations. The sets of weighings taken at

different times are grouped together, for the purpose of getting a mean result, according to the total gain or loss of the whole set of samples. In this way the differences of temperature at which the soil-fractions and the calcium chloride solutions were in equilibrium exercise no influence on the results. Thus three series of weighings with concentration of solution varying between $CaCl_2 16H_2O$ and $CaCl_2 23H_2O$ gave an average gain per bottle of ·0041, ·0061, and ·0068; the mean of these weighings is given in the table as "18. Moist atmosphere." The whole series of weighings has been grouped under the six atmospheres given in Table 10. The results given in Table 10 were obtained with two soils; the six fractions of each included altogether eight duplicates, so that each column gives a mean of the results with three or four separate samples. It may be mentioned in passing that the figures in Tables 8—11 are based on altogether nearly 2000 weighings.

Again, in calculating the results of the first series of experiments it was found that the soils themselves held more moisture, and in some cases much more moisture than the quantities calculated from the contents of their respective fractions. This is shown in Table 9, where the five soils are given separately. It will be seen that of the 25 comparisons only five show less moisture found than calculated, and the excess of found over calculated is very considerable in many cases.

TABLE 9.

Soil number......	17		28		29		27		30	
	Calculated	Found	Calculated	Found	Calculated	Found	Calculated	Found	Calculated	Found
9. Normal atmosphere	1·44	2·23	1·55	2·24	1·02	1·50	·51	·81	·32	·42
17. Moist atmosphere .	2·99	3·75	2·85	3·84	2·30	2·84	1·17	1·48	·69	·82
22. ,, ,, ...	4·37	5·22	4·55	5·63	3·62	4·12	1·76	2·11	1·17	1·11
37. ,, ,, ...	4·80	6·13	5·28	6·44	4·01	4·36	1·88	2·33	1·31	1·01
74. Very moist ,, ...	6·21	8·00	7·23	7·72	5·86	5·65	2·62	2·39	2·15	1·14

This is what might be expected if it be borne in mind that in the determination of the moisture capacity of the finer fractions the material is aggregated together in what must be a very unfavourable condition for the exercise of surface action, whilst in the soil itself the coarser particles serve to keep the finer ones apart, and are probably coated over with them. To give the finer material a fairer field for its hygroscopic activity in the second series of experiments the three finer fractions of soil were well mixed up with water and then distributed

over coarse particles of sand over ·2 mm. in diameter. Moreover, instead of taking 1 gram for each sample, quantities were taken varying from 2 grams for the coarsest down to as little as ·14 gram for the finest particles.

This, however, has introduced a difficulty into the calculations, because, although the hygroscopic power of the finer grades is immensely greater than that of coarse quartz sand, yet the large quantity of this that needed to be taken makes one hesitate to utterly neglect its influence. On the other hand, if the use of the coarse particles is to bear a coating of the finer, it does not seem right to take account of their own natural surface action also. On the whole it has seemed best to give the results without any correction for the action of the sand. But it will be seen that the results for the finer three grades cannot now be compared with that for fraction III.

TABLE 10.

Fractions	I	II	III	IV	V	VI
Mean diameter in mikrons	300	80	24	8	3	$1\frac{1}{3}$
Organic matter per cent.	1·0	—	5·5	11·0	16·0	23·0
Moisture absorbed per cent.:						
8. Normal atmosphere	·07	·05	·20	·66	1·10	1·53
10. ,, ,,	·11	·09	·29	1·02	1·80	2·30
18. Moist atmosphere	·17	·15	·59	2·10	3·40	5·83
33. ,, ,,	·26	·26	·99	3·32	6·16	12·04
64. Very moist atmosphere	·35	·31	1·29	4·12	7·70	17·32
95. ,, ,, ,,	·37	·33	1·35	4·67	8·87	22·29
Mean of all	·22	·20	·79	2·65	4·84	10·22
Allow for Organic	—	—	·74	1·48	2·15	3·10
Due to Surface	—	—	·05	1·17	2·69	7·12
Moisture Multiple	—	—	—	—	**2·3**	**2·6**
Mean of 8, 10, 18	·12	·10	·36	1·26	2·10	3·22
Allow for Organic	—	—	·33	·66	·96	1·38
Due to Surface	—	—	·03	·60	1·14	1·84
Moisture Multiple	—	—	—	—	**1·9**	**1·6**
Surface Multiples diameter^{-1}	—	—	—	—	**2·7**	**2·3**
Surface Multiples diameter$^{-\frac{1}{2}}$	—	—	—	—	**1·9**	**1·7**

The soils chosen for the second series of experiments contained very little organic substance in the two coarser fractions, and it is not possible in the figures given in Table 10 to calculate the influence of the organic substance from the hygroscopic capacity of fraction I or fraction II. A

provisional assumption has been made according to which nearly all the influence of fraction III is attributed to its organic substance, in order to give ratios for the surface action of the smaller particles. This is a very arbitrary assumption, and the figures of course do not harmonise well with those on Table 8, but on the other hand it seems best to treat each set of figures by themselves in the first place, and moreover it is possible to allow some latitude in the amount of influence ascribed to organic substance without producing a very large effect on the moisture multiples due to surface.

The general aspect of Table 10 suggests that we have here a lower series of figures than in Table 8. This is, however, chiefly due to the lower percentage of organic substance in each fraction, and also in part to a greater weight given in the means of Table 10 to the atmospheres with less moisture. The order of moisture in the two series is roughly as indicated by the numbers. The mean of all in each table will probably be similar; but the mean of 8, 10, 18 represents a much drier atmosphere than 9, 17, 22. It must, however, be confessed that the results are a little disappointing as to the influence of distributing the finer fractions on coarse sand.

EXPERIMENTS WITH GROUND SAND.

In Table 11 are given the results with the ground down sand fragments. Most of the figures obtained are very small; the differences between fractions I, II, III are of the order of experimental error. Fraction IV*a* consisted of 2 gr. in a weighing bottle by itself; it absorbed

TABLE 11.

Fractions	I, II, III	IV *a*	IV *b*	V	VI *a*	VI *b*
Mean diameter in mikrons	—	8	8	3	1⅓	1
Moisture absorbed per cent.:						
8. Normal atmosphere	·01	—	·06	·09	·37	·81
10. ,, ,,	·03	·05	·17	·25	·95	1·49
18. Moist atmosphere	·04	·06	·20	·29	1·76	4·26
33. ,, ,,	·07	·11	·51	·65	4·10	11·90
64. Very moist atmosphere	·08	·16	·54	·74	6·90	19·0
95. ,, ,, ,,	·10	·17	·74	1·04	8·39	27·3
Mean of all	·05	·09	·37	·51	3·74	11·3
Moisture Multiple	—	1·8	4·1	1·4	7·3	3·0
Mean of 8, 10, 18	·03	·05	·14	·21	1·02	2·2
Moisture Multiple	—	1·7	2·8	1·5	4·9	2·2

very little more water than the coarser grades. Fraction IV*b* was almost identical material ·75 gr. mixed with 5 gr. of coarse sand. If from the figures for this fraction one deducts a proper allowance for the coarse sand, the remainders are approximately equal to the figures for IV*a*. In column V also the deduction for the 5 gr. coarse sand with which the fraction is mixed would make a great proportional difference; and these figures for fraction V, which are the means of fairly concordant determinations on duplicate specimens, are very low. It will be observed that in making the surface action of fraction III in Table 10 equal to that given on Table 11, we get far higher figures for the surface of mineral fragments in fractions IV and V in Table 10 than the mineral fragments in Table 11 actually give. (See 1 under general conclusions below.)

The fractions VI *a* and VI *b* are samples of fine material from the levigation and elutriation of coarse washed sand respectively above and below 2 mm. in diameter. There is a slight difference in dimensions as given, but for the great differences between the two samples there is no adequate reason to assign. No other pair of samples has given such discrepancies. The figures are given in the table because they furnish an extreme example of the way in which the water content of the finest material goes up in very moist atmospheres. The same result in far less degree can be observed in Tables 8 and 10 for fraction VI in the very moist atmospheres. As, however, it is there masked by the organic matter, there is set forth in Table 12 the result of grouping together the results of both series of experiments for fractions IV, V, VI for the very moist atmospheres, and making an allowance for organic substance exactly as it is done in Tables 8, 10. We see then how the moisture multiple V/IV rises to 2·6, and that for VI/V to 3·8, which are far higher figures than are met with elsewhere.

·69

TABLE 12.

Fractions	IV	V	VI
Mean diameter in mikrons	8	3	1⅓
Organic matter per cent.	12·6	17·5	25·2
Moisture absorbed per cent.:			
74, 64, 95. Very moist atmospheres	4·75	8·13	19·93
Allow for Organic	3·38	4·61	6·69
Due to Surface............................	1·37	3·52	13·24
Moisture Multiple	—	2·6	3·8

CONCLUSIONS.

The following are the most important general conclusions that can be drawn from the experiments:

1. The organic substance not only has a powerful direct influence in attracting moisture, but it also acts indirectly, so that the joint effect of the organic substance and the surface of the mineral particles is not merely an additive property. The organic material probably serves to keep the finer grades of mineral matter apart and free to exercise surface attraction far more effectually than the coarser mineral particles are able to do.

2. It appears that the organic substance in different fractions has not always the same hygroscopic power. For example, on comparing the figures for fractions I and III in Table 10, it is seen that the moisture absorbed by the latter is never so much as four times that absorbed by the former, although the organic substance is present in more than five times as large a proportion, and it is impossible to believe that the mineral particles of fraction III can exercise less effect than those of fraction I. These results are the same if the figures are taken for the two soils separately or for the mean as given in Table 10.

3. Mineral particles of the same size in different soils have not identical hygroscopic power. This result, which is in harmony with the results given above (pp. 307—310) based on the coefficients of correlation of the whole of the Dorset soils, is clearly seen in Table 13. In Table 10 the figures given are the mean of experiments with two soils—No. 37, taken from the Gravel, and containing 6·9 per cent. soluble minerals, of which 3·04 is iron oxide; and No. 33, from the Wealden beds, which gives 10·3 per cent. soluble minerals, 3·88 per cent. being iron oxide. No. 37 also contains less organic matter than No. 33, but fractions V and VI of the former contain more organic substance than the corresponding fractions of the latter. The separate results are given in Table 13, where it is seen that, while 33 V contains only about four-fifths of the organic substance contained in 37 V, it absorbs about one-eighth more water in the average of the six atmospheric conditions. The "clay" of 33 (fraction VI) contains only about three-quarters of the organic substance contained in that of 37, but it has about an equal capacity for water. This is evidently due to the greater hygroscopic power of the mineral particles of the more ferruginous soil.

4. The finest grade particles, especially the clay fraction VI, show specially high attraction for water in atmospheres of extreme moistness,

and the moisture multiple VI/V is accordingly a function of the atmospheric moisture. Thus in Table 10 this factor is given as 1·6 for the atmospheres 8, 10, 18. But it rises to 2·9 for the moister atmospheres 33, 64, 95, and, as shown in Table 12, it rises to 3·8 for the very moist atmospheres 64, 76, 95. That this is an effect of the mineral particles is clear from Table 11, for, neglecting the altogether abnormal fraction VI *b*, we get increasingly high moisture multiples in the moist atmospheres for VI *a*/V.

TABLE 13.

Soil number	37	38	37	33
Fraction	V	V	VI	VI
Organic matter per cent.	17·5	14·1	26·4	19·7
Moisture absorbed per cent.:				
8. Normal atmosphere ...	1·05	1·15	1·30	1·73
10. ,, ,, .	1·68	1·92	1·80	2·63
18. Moist atmosphere	3·27	3·54	5·51	5·92
33. ,, ,, ...	5·60	6·72	12·18	12·00
64. Very moist atmosphere	7·48	7·88	17·31	17·32
95. ,, ,, ,,	8·03	9·59	22·85	22·06
Mean of all	4·52	5·13	10·16	10·28

5. It follows from the foregoing that the attraction of mineral particles for moisture cannot be strictly expressed as simply proportional to their surface, and it is readily seen that many apparent irregularities in the tables are due to the causes operating in accordance with 1, 2, 3, 4 above. But within certain limits as to moisture in the atmosphere, and in spite of the disturbing influence of other factors such as the varying attraction of the organic material, its indirect action, and the special hygroscopic action of iron oxide and perhaps other soluble minerals, there is a regularity in what is here called the moisture multiple, so that it tends to assume a value inversely proportional to the diameter raised to the two-thirds power:

$$\text{moisture multiple} = (\text{diameter multiple})^{-\frac{2}{3}}.$$

This does not at first seem like a surface ratio. It is a well-known mathematical fact that similar solids have surfaces varying as the square, and volumes as the cube of their linear dimensions. Treating the density as a constant, this leads to the well-known proposition that a gram say of material of uniform size and shape will have its total

surface increased twofold if, the shape remaining the same, the linear dimensions of each particle are halved; we get eight times as many particles, each having a quarter of the surface of the large, and therefore the total surface $8 \div 4 = 2$.

But it is not difficult to convince oneself that there is a considerable probability that, if the smaller particles are derived from the larger by fracture and attrition, they will on the whole be shaped so as to offer less surface than if they were reduced images of the coarser ones. It is also the writer's impression, from observation when measuring the particles, that the smaller ones are apt to have the two dimensions that are at right angles to the axis of the microscope more nearly equal than in the case of the larger pieces.

However this may be, it appears as if the use of the two-thirds power ratio was most suitable for the majority of cases, but in the case of the finest particles in a very moist atmosphere the increase in moisture gained proceeds at a far higher rate.

A METHOD FOR THE DETERMINATION OF CARBONATES IN SOILS.

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THE methods usually employed for estimating calcium carbonate in soil are all subject to more or less serious practical difficulties when the percentage of lime falls below 0·5.

In gravimetric methods, in which the carbon dioxide set free by acid has first to be boiled out of solution and then perfectly dried before absorption by potash, a very small weight of carbon dioxide is estimated by the gain in weight of a comparatively heavy absorption apparatus.

The volumetric method of Scheibler also cannot be used for soil containing only 0·5 per cent. of lime because all the carbon dioxide remains in solution in the decomposing acid.

The method devised by Hall and Russell[1] (in which the lime is decomposed in an exhausted apparatus, and the carbon dioxide set free calculated from three readings of pressure, taken (1) before the addition of acid, (2) on equilibrium being established after the acid is added, (3) on equilibrium being established when the gas is allowed to expand into a further exhausted and known volume) gives very accurate results; but much shaking is required in order to overcome the supersaturation of the decomposing acid with the carbon dioxide, and hence each determination occupies a considerable time, and leakages are apt to occur unless the taps are very perfect.

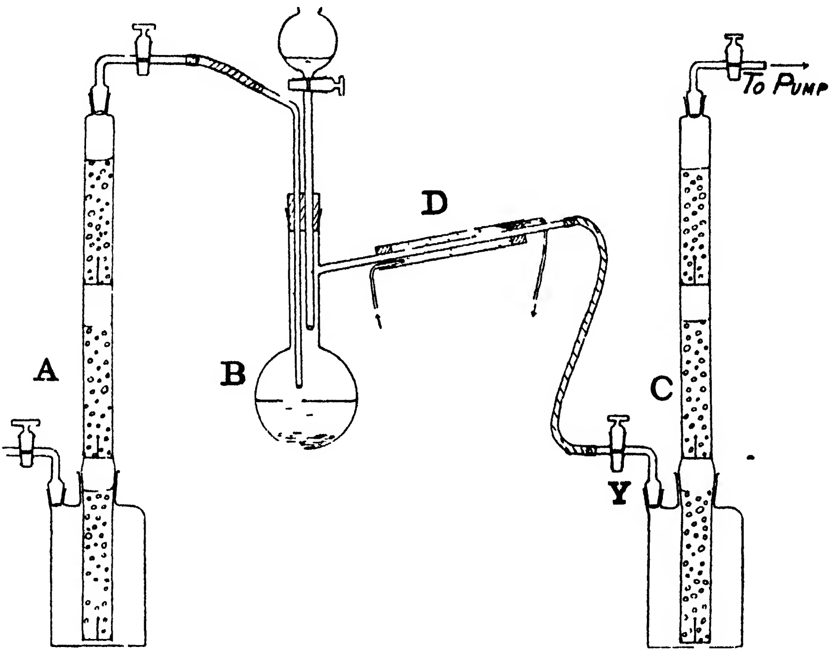
Brown and Escombe[2] in the course of their work on carbon assimilation of plants have shown that, by a modification of Hart's method of double titration for estimating sodium carbonate in the presence of

[1] *Trans. Chem. Soc.* 1902, Vol. LXXXI. p. 81.

[2] *Phil. Trans. Roy. Soc.* 1900, Vol. CXCIII. pp. 289—291.

sodium hydrate, quantities of carbon dioxide, varying from 1 to 100 c.c. and contained in 100 c.c. of 4 per cent. sodium hydrate solution, can be determined within ·2 c.c. of the quantity added.

Whilst making use of this method for determining the varying amounts of carbon dioxide in the atmosphere it was suggested to me by Mr A. D. Hall, M.A., that a modification of this might be employed for determining calcium carbonate in soil, which led to the following method being devised.



The apparatus as shown in the diagram consists of:—

A. A Reiset absorption apparatus containing 100 c.c. of a 4 per cent. sodium hydrate solution for washing the air free from carbon dioxide.

B. A Jena flask, in which the soil to be treated is put; the flask is provided with a side tube.

C. A second Reiset apparatus containing 100 c.c. of a 4 per cent. sodium hydrate solution for absorbing the carbon dioxide set free in B.

D. A condenser for cooling the air passing into C to prevent the lubricant of the inlet tap being melted.

Procedure:—A weighed quantity of soil is put into the flask B and shaken up with 75 c.c. of carbon dioxide free water (any weight of soil

may be used up to 50 grams, containing not more than 0·5 gram of lime); the apparatus is now connected up as in the figure except that the end Y of the rubber tube is connected directly with the pump, and a stream of air is drawn through the apparatus, so that all the atmospheric carbon dioxide is swept out; the pump is stopped and the Reiset C introduced between Y and the pump, and the pump started again, so that a steady stream of air free from carbon dioxide is drawn through the apparatus. 20 c.c. of strong hydrochloric acid are now run into B by means of the dropping funnel, and the contents of B gradually brought to the boiling point; the boiling is continued for 20 minutes to ensure all the carbon dioxide being swept into the Reiset C.

The titration is carried out in the lower part of the Reiset apparatus, into which the contents of the absorbing tube are washed, phenol-phthalein is added and normal hydrochloric acid run in until the pink colour begins to fade, then decinormal hydrochloric is run in until the colour is completely discharged, the reading of the decinormal hydrochloric acid is now taken, methyl-orange is added, and the titration continued until the methyl-orange shows an acid reaction; a second reading of the hydrochloric acid is now taken.

The difference between the two readings gives the volume of decinormal hydrochloric acid required in the equation,

$$NaHCO_3 + HCl = NaCl + H_2O + CO_2,$$

and hence we get the weight of calcium carbonate originally present in the soil.

The object of employing normal hydrochloric acid in the first part of the titration is to prevent unnecessary dilution, but the liquid must be kept in motion so that the acid is never in excess at any point with consequent evolution of CO_2.

The presence of aluminium and iron has been shown to interfere with the sharpness of the second colour reaction, consequently the sodium hydrate employed must be prepared from metallic sodium.

In order to get an exact reading at the end of the second titration a standard solution of methyl-orange, contained in a vessel of the same shape and size, and having an arbitrary tint of acidity should be employed, with which to compare the tint.

These precautions are some of those suggested by Brown and Escombe.

A preliminary blank experiment must be carried out in order to correct for:—

(i) The amount of carbon dioxide originally present in the 100 c.c. of sodium hydrate used in the Reiset.

(ii) The CO_2 contained in the air in the Reiset apparatus C before the soda solution is run into it.

(iii) Any CO_2 in solution in the 20 c.c. of acid employed for decomposing the lime.

The following table gives the results of a series of experiments carried out for the purpose of testing the accuracy of the method; weighed quantities of ground Iceland spar, or a known volume of a solution of sodium carbonate, were treated by the above method, and the weight of calcium carbonate or sodium carbonate calculated from the carbonic acid absorbed.

No. of Experiment	Weight of $CaCO_3$ taken (grams)	Weight of $CaCO_3$ found (grams)
	0·057	0·056
	0·105	0·104
	0·242	0·245
	0·542	0·541
	0·564	0·559
	25 c.c. = 0·0250 Na_2CO_3	0·0248 Na_2CO_3

The absorption of carbon dioxide in the Reiset apparatus is very perfect; the rate at which air may be passed through and still be completely freed from carbon dioxide is only limited by the overflow of the sodium hydrate solution.

When a series of calcium carbonate estimations have to be made the method is reliable and quick; one determination lasting about 45 minutes; but when only isolated determinations have to be made, the method of Hall and Russell is more expeditious because of the time involved in the preparation of solutions and other preliminaries.

The above method was employed for the estimation of calcium carbonate in some soils taken from the Royal Agricultural Society's farm at Woburn; the following table shows the results obtained: the first column gives the name of the plot from which the soil was taken; the second gives the weight of soil employed; the third gives the volume of acid in duplicate experiments used in the titration; the fourth gives the volume of acid required in a blank experiment; the fifth gives the calculated percentages of calcium carbonate.

It will be seen that the duplicates agree except in one instance (in the first depth of plot 3 of the Rotation field), in which one low figure was obtained.

Plot 2 A in the Stackyard field is the well-known 'acid' plot, which has been continuously manured with ammonium salts, the fresh soil of this plot gives an acid reaction with litmus.

The percentage of calcium carbonate found in the first depth of this soil (0·053) was lower than that found in the first depths of any of the other plots but yet seemed inconsistent with its acid reaction.

Sample of soil	Weight of soil in grams	Vol. of $\frac{N}{10}$ HCl in c.c.	Vol. of $\frac{N}{10}$ HCl in Blank Expt.	% of $CaCO_3$
Stackyard 2A, 1st depth, 1903	50	11·5, 11·4	8·9	0·053
,, 2A, 2nd ,, 1903	50	11·1, 11·1	8·9	0·044
,, 3, 1st ,, 1903	50	12·5, 12·4	8·9	0·070
,, 3, 2nd ,, 1903	50	10·9, 11·1	8·9	0·042
,, 4, 1st ,, 1876	50	11·6, 11·5	8·9	0·087
,, 4, 2nd ,, 1876	50	10·9, 10·9	8·9	0·066
Rotation 3, 1st ,, 1903	50	11·9 (11·3), 12 1	7 3	0 089
,, 3, 2nd ,, 1903	50	10·9, 10·9	7·3	0 071

It was thought that this might be due to carbon dioxide being occluded by the soil particles; in order to test this, 50 grams of soil were digested with hydrochloric acid, filtered, washed and then stirred up with some water saturated with carbon dioxide, and allowed to dry in the air at the ordinary temperature; the carbon dioxide was then estimated by the method, when it was found that no carbon dioxide had been occluded.

A further experiment was carried out to test this point: 50 grams of plot 2 A were placed in the flask of the apparatus with water only, no hydrochloric acid being added, the mixture was boiled, and any gas evolved passed through the Reiset tower; it was found that no carbon dioxide had been absorbed; hence we must conclude that the calcium carbonate is genuinely present, and its presence will explain the fact that when this soil is stirred up with water, and the mixture kept for some weeks, the acidity slowly disappears, owing to the interaction between the acid and the carbonate.

THE RECENT WORK OF THE AMERICAN SOIL BUREAU.

By EDWARD J. RUSSELL, D.Sc. (Lond.),
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Since its inception in 1894 the American Soil Bureau has investigated many important problems and obtained results which are now common knowledge in this country, but its earlier Bulletins are altogether eclipsed in interest and far-reaching significance by a series recently published. In presenting an account of these it will be most convenient to set out first the purely scientific part of the work, and then the practical applications. This is the logical order and also the order in which the results were actually obtained.

Soil Fertility.

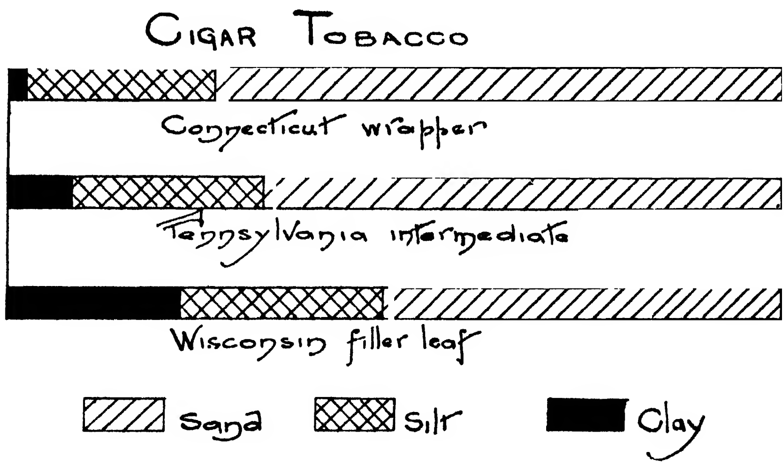
Jethro Tull in 1733 published some consistent speculations on fertility based on the assumption that earth is the proper food of plants. If the surface of the soil is increased, the "pasture of the plant," as he quaintly terms it, increases also, and a greater yield is obtained provided the moisture and temperature conditions are favourable. Dung and cultivation both increase the surface, the former by fermentation, the latter by actual attrition; both methods can be used, but cultivation is better and cheaper—a man's wages then being 1*s.* a day—and dung may even be dispensed with.

From the close of the 18th century the development of chemistry became extremely rapid and agriculture was soon brought within its sphere.

Many of the agricultural investigators were in the first instance chemists, and chemical conceptions of fertility naturally began to assume greater and greater predominance. These conceptions have been and still are extremely useful, but we recognise now that they are not complete.

In America, on the other hand, soil fertility has been studied by physicists and physical chemists with the result that greater stress is laid on physical than on chemical properties, the latter in fact being almost disregarded.

The main ideas underlying much of the present work of the Bureau are foreshadowed in a bulletin published by Whitney in 1892[1], when he was Professor of Geology and Soil Physics at the Maryland Agricultural College, and Physicist at the Experiment Station. He examined a number of soils of known productiveness, and showed that in passing from type to type the agricultural properties are closely correlated with the texture of the soil as revealed by mechanical analysis. Physical characteristics, and especially texture, regulate the temperature, moisture content, and aëration, in short the "climate" of the soil, and their significance in determining the distribution and yield of crops must therefore be of the same order as climate in the ordinary sense of the word. They are the predominant factors in fertility.



This thesis was further developed in 1898[2]. Typical tobacco soils from the various States were investigated, and a close connexion found between the quality of the crop and the texture of the soil. High quality ("wrapper") tobacco was produced on soil containing a large quantity of sand and a small proportion of clay, whilst low quality crops ("filler" tobacco) were associated with heavier soils, containing

[1] "Some Physical Properties of Soils in their Relation to Moisture and Crop Distribution," Whitney, Weather Bureau, *Bull.* No. 4, 1892.

[2] "Tobacco Soils of the United States," Whitney, Division of Soils, *Bull.* No. 11, 1898.

more clay and silt. These facts are well illustrated in the accompanying diagram, taken from Whitney's paper. By no scheme of manuring can the heavy soil be made to produce a wrapper tobacco, nor is it good economy to attempt to grow large crops of the filler type on soils naturally adapted to carry small crops of higher class tobaccos.

So successful was mechanical analysis in classifying these and other soils that it was adopted as the basis of the elaborate Soil Survey of the United States now in progress. An area of about 400 square miles is assigned to one or two experts and thoroughly covered by them; they then draw up reports which are issued, with an introduction by Professor Whitney, by the government. A pleasing feature about the reports is that each separate one is signed by the assistants actually in charge, instead of being anonymous publications or issued only in the name of the chief.

After stating the position and boundaries of the area under survey, a brief account of its history is given with special reference to agricultural development. A general statement about the climate follows, with statistics of mean monthly temperatures, rainfall, and dates of the latest spring and earliest autumn killing frosts. The geology of the district is next dealt with, and finally the separate types of soil are described in some detail. The type is considered as a whole, and particular care is taken to ascertain which crops are most successful. The central idea seems to be that to every type of soil in a given locality particular classes of crop are adapted, and it is no use, or at any rate it is not economical, to kick against the pricks and try to grow anything else. This does not mean that agriculture becomes stereotyped; fresh crops are continually being introduced by the Bureau of Plant Industry and the Soil Bureau proceeds to ascertain the soils to which they are best suited. For the purpose of the Survey it is considered sufficient to make full mechanical analyses, chemical analyses not as a rule being carried out.

In studying the methods and results of the Survey one has to bear in mind that it deals exclusively with types and not with variations within those types. However much we might like to know the chemical composition of the soil, we must certainly agree that the differences between the types are brought out more clearly and the types are more definitely described by a mechanical than by a chemical analysis; numerous instances of this could be quoted from English soils. In fact our whole conception of type usually rests on physical considerations.

Whitney and his co-workers, however, early realised that a mechanical

analysis does not completely solve the problem. In some cases it broke down entirely, and classed as identical soils of widely different agricultural value; the Florida soils are of such interest in this connexion that they were dealt with separately[1]. Some of these soils, the "pine lands," naturally produce good grass and pine and are excellent for market garden purposes. Their most remarkable feature is the evenness of their water content, about 4 °/ₒ is present, and there is but little variation throughout the whole season. The "hammock soils," on the other hand, naturally produce oak, hickory, dog-wood, and other hardwood trees and are suited for general agricultural purposes and "filler" tobacco. They contain about twice as much water as the pine soils, but the amount is not constant and fluctuates considerably. The Etonia scrub differs widely from both; it borders on the pine land, but the line of demarcation is very sharp. No grass is found, and only the most hardy desert plants grow, they form a dense growth about 5 ft. high, with thick leaves turned edgewise to the sun and in fact all the characteristics of desert vegetation. The few attempts to cultivate these soils have failed. No three soils could very well show greater vegetation differences, yet mechanical and chemical analysis represent them as identical.

Kind of land	Organic matter	Gravel 2–1 mm.	Coarse sand 1–·5 mm.	Medium sand ·5–·25 mm.	Fine sand ·25–·1 mm.	Very fine sand ·1–·05 mm.	Silt ·05–·01 mm.	Fine silt ·01–·005 mm.	Clay
Etonia scrub	1·24	·23	3·84	27·43	58·60	7·60	·55	·20	·87
High pine land	1·82	1·46	5·78	23·89	45·11	18·42	·96	·38	1·56
Grey hammock. .	1 84	·36	3·29	19·75	52·17	19·08	·66	·50	1·68

The subsoils show a similar identity.

Average amount of water present (April and May).

Etonia scrub .... 2·4 °/ₒ,
High pine land .... 3·7 °/ₒ,
Hammock .... 8·2 °/ₒ.

There is no apparent reason why desert conditions should prevail on the scrub and not on the pine land, nor is it intelligible why the hammock should contain so much water.

[1] "Preliminary Report on the Soils of Florida," Whitney, Division of Soils, *Bull.* No. 13, 1898.

The soils are all poor, and the scrub is poorest of all, but the differences revealed in the table will scarcely account for the great differences in vegetation.

Whitney quotes other instances where present methods break down in the Catalogue of Soils[1], and in some of the later bulletins[2].

	K_2O	CaO	MgO	P_2O_5	N
Etonia scrub	·003	·030	·013	·008	·028
High pine land	·007	·060	·020	·140	·028
Grey hammock	·009	·090	·036	·090	·042
Average of American soils (Hilgard)	·216	·108	·225	·113	

One would hardly expect a mechanical analysis to give a complete account of a soil, however. The important factors are the temperature, moisture content, and aeration of the soil, and whilst these are mainly, they are by no means completely determined by the ultimate structure as revealed by mechanical analysis. Temporary artificial aggregates, behaving like natural ones, can be obtained by cultivation or manuring, yet no account of them is taken in mechanical analysis. Moreover the depth of the water-level and the nature of the intermediate strata are matters of the highest significance. The factors concerned interact in an unknown but complex way, and even if the separate effects were determined it would be a difficult problem to integrate them with certainty.

As a step in this direction, Whitney devised[3] and Briggs developed[4] an electrical method for finding the amount of water in the soil. The advantages of a method that allows determinations to be made *in situ* are obvious: not only can the records be made practically continuous, but after the apparatus is planted no further disturbance of the soil takes place. Carbon electrodes are buried in the soil, a rapidly alternating current is passed between them, and the resistance measured on a Wheatstone bridge. The electrical conductivity is stated to be nearly proportional to the square of the water content[5]; for more exact determinations the proper exponent can readily be ascertained.

[1] *Bull.* No. 16, 1899; see especially Lafayette, p. 115.

[2] See *Bull.* No. 22, p. 55.

[3] Weather Bureau, *Bull.* No. 4, p. 88. See also Gardner, "Electrical Method of Moisture Determination in Soils," *Bull.* No. 12, Division of Soils, 1898.

[4] Briggs, "Electrical Instruments for Determining the Moisture, Temperature, and soluble Salt Contents of Soils." *Bull.* No. 15, Division of Soils, 1899.

[5] *Bull.* No. 12, p. 15.

The theoretical basis of the method is not discussed in any of the bulletins I have seen, but it is somewhat as follows. The conductivity of a solution depends among other things on the number of ions present in a given volume, and this method assumes that

(1) for a given water content the number of ions in the soil solution is always the same,

(2) as the water increases, the ions increase, but in a much greater ratio, and as the water decreases the ions decrease and again to a much greater extent.

The method only holds so long as the soil contains somewhere about the optimum amount of water; it breaks down when there is an excess or great deficiency, but this of course does not prejudice its use. Keeping within these limits one can readily accept the second assumption and conceive a solution behaving in the manner indicated; it is nearly saturated with substances that readily dissociate on dilution, and the effect of adding a little water is to increase dissociation to a considerable extent and so increase the number of ions. On the other hand, when water is removed the ions unite again and the conductivity decreases. The difficulty is to accept the first, and to suppose that the concentration of the ions is constant for a given water content. If a soil contains 15 $^{\circ}/_{\circ}$ of water one day in June and the same amount one day in September we have to assume that the concentration of the dissolved substances, or at any rate of the ions, is the same on both occasions, and that any changes which may have taken place, nitrification, removal of dissolved matter by plants, etc., are either so small as to be negligible or else counterbalance one another.

Strange as this doctrine is, it is nothing to what follows. In 1903, Whitney and Cameron published a remarkably curious paper on "The Chemistry of the Soil as related to Crop Production[1]," wherein Chemistry, which had been relegated to the background in the previous work on Soil Types, is dismissed altogether. Amongst other novel propositions in this paper are:—

1. The solution constituting the soil moisture may be regarded as the culture solution of the plant and is normally sufficient for the plant's requirements.

2. This solution is of the same order of composition and concentration in all soils, such differences as exist cannot be correlated with differences in crop production.

[1] Bureau of Soils, *Bull.* No. 22. (In 1901 the Division of Soils was converted into the Bureau of Soils.)

3. The function of the soil is to hold up this solution and supply it to the plant.

4. A productive soil is one which supplies the solution in proper amount and must therefore possess certain physical properties, but its chemical composition is not of primary importance.

5. The function of fertilisers is not to supply plant food, but rather to modify the physical condition of the soil.

6. On the average farm the great controlling factor in the yield of crops is not the amount of plant food in the soil, but is a physical factor the exact nature of which is yet to be determined.

The first proposition is supported by some old experiments of Birner and Lucanus[1], who grew plants to maturity in well-water. In a later bulletin Whitney and Cameron[2] also grew plants in an aqueous soil extract.

The second proposition is liable to be misunderstood owing to an ambiguous statement referred to later on. The authors do not mean, I think, that the solutions are identical, but that they are of the same order of concentration. It was not found practicable to analyse the actual soil moisture in more than a few cases, owing to the extreme difficulty of separating it from the soil. Filtering methods caused changes in concentration, and the problem seemed insoluble till Briggs devised a very ingenious centrifugal apparatus by which much of the moisture is thrown off and can be collected. It was noticed that soils show great differences in the ease with which they part with their moisture even when the initial content is the same, and this important difference is being investigated, but in no case was the apparatus as efficient as a plant in removing the moisture. Analysis of the solution showed:—

	Soil solution, parts per million				Dry soil, parts per million			
	PO_4	NO_3	Ca	K	PO_4	NO_3	Ca	K
Sassafras loam, New Jersey								
Wheat, good	7·20	7·20	44·40	33·60	1·35	1·35	8·34	6·31
„ poor	7·00	·40	26·90	24·40	1·40	·08	5·38	4·88
Leonardtown loam, Maryland								
Wheat, good	6·30	1·44	16·20	21·60	1·38	·32	3·56	4·75
„ „	8·40	4·08	21·60	38·40	1·48	·72	3·80	6·75
„ poor	9·75	4·80	8·50	19·25	2·45	1·21	2·12	5·10

[1] *Landw. Versuchs. Stat.* 1866, VIII. 128.

[2] Investigations in Soil Fertility, *Bull.* No. 23, 1904.

The authors state that it is impossible to correlate these differences with the differences in crop production.

The method generally adopted was to vigorously stir 100 grms. of soil for three minutes with 500 c.c. of water, allow to stand for 20 minutes, decant and filter under pressure through a Chamberland-Pasteur filter[1]. The first 150 c.c. are rejected owing to absorption by the filter, but equilibrium is then set up and the rest of the solution filters unchanged. The phosphoric acid, nitric acid, potassium, and calcium are determined by colour reactions, rapid methods being indispensable where several hundred samples have to be examined.

It is admitted that the solution thus obtained is not a very definite thing for it neither quite represents the soil moisture nor is it a saturated solution of the soil constituents. But the method is believed to give comparable results, and these are all that are wanted. The colour tests are said to be very reliable. Messrs Taylor and Mooney examined certain types of soil showing marked differences in productiveness, 147 soils were investigated and the results are set out in the paper. The mean results are given in parts per million of dry soil as:—

Phosphoric acid (PO_4)...	7·64
Nitric acid (NO_3)	5·47
Calcium (Ca).......	11·67
Potassium (K)	22·74

Whitney and Cameron add, "While these figures will undoubtedly vary somewhat as a result of wider investigations, it is believed that they represent closely the average figures for the great majority of cultivable soils as regards these several constituents, which the procedure used in this investigation will show." This ambiguous sentence might seem to imply that the solutions are fundamentally identical, but the figures will not bear this interpretation. I take it the authors mean that these figures indicate the *order* of concentration, not the *actual* concentration. The highest and lowest values are:—

	Highest	Lowest
Phosphoric acid...	40·60	·59
Nitric acid	62·00	Trace
Calcium	102·85	Trace
Potassium	62·20	4·93

[1] Briggs, "Filtration of Suspended Clay from Soil Solutions," *Bull.* No. 19, 1902.

If we group the figures to show their distribution we find in the case of phosphoric acid the number of instances where there are

Less than 5 parts per million of dry soil	=120	or	27·97 %
5 to 10 ,, ,, ,,	=193	,,	44·99 ,,
10 ,, 20 ,, ,, ,,	=105	,,	24·47 ,,
20 ,, 30 ,, ,, ,,	= 8	,,	1·86 ,,
30 ,, 40 ,, ,, ,,	= 3	,,	·70 ,,
	429		99·99 %

A similar distribution can be worked out for the other constituents.

Abundant proof is given that the differences in the chemical composition of the solutions are in no way related to the productiveness of the soils; to take two instances out of many:—

	PO_4	NO_3	Ca	K
Cecil clay, 25 to 30 bushels of wheat	11·04	2·87	22·25	44·16
,, 2 to 3 ,, ,, ...	12·83	Trace	22·49	35·71
Cecil sandy loam, 15 to 20 bushels of wheat	—	·92	20·69	32·37
,, ,, 2 ,, ,,	—	·66	19·58	34·13

or if instead of taking individual examples we take the mean of a number:—

	PO_4	NO_3	Ca	K
Sassafras loam, 6 good wheat soils	8·36	5·46	12·35	21·46
,, ,, 6 poor ,, ,, ..	5·60	8·97	24·86	21·05

Whitney and Cameron then proceed to consider the functions of fertilisers. They argue that fertilisers may temporarily, but cannot permanently, increase the amount of dissolved matter in the soil moisture. This latter being a saturated solution of all the substances occurring in the soil it follows from Nernst's well-known law that addition of the ions of potassium would simply throw some potassium out of solution by causing recombination of dissociated or hydrolysed solutes. The temporary increase is shown in the following case:—

	PO_4	NO_3	Ca	K
Tobacco field, Windsor sand, Unmanured strip	3·85	4·90	8·63	20·90
,, ,, 400 lbs. of 'bone and potash'	6·60	7·70	9·90	25·74
Gain, parts per million of dry soil	2·75			4·84

The samples are taken to a depth of 12″; and we might estimate the gain at about 10 lbs. of phosphoric acid (P_2O_5) and 18 lbs. of potash (K_2O). Unfortunately we are told nothing about the "bone and potash," but it is obvious that a good part of the added fertiliser is in the soil moisture. It is stated to have been "amply demonstrated" that these increases "disappear with surprising rapidity," but the proofs are not set forth. This is very unfortunate, because the point is an important one.

They find other reasons in support of their contention that fertilisers do not supply plant food. The effect of fertilisers is not cumulative; at Rothamsted, for instance, annual additions of manure far in excess of actual plant requirements only maintain a high crop and do not indefinitely increase it. Nor are fertilisers always consistent in their action. Instances are quoted where on the same soil phosphates give a considerable increase in crop some years but none at all in others, they even sometimes decrease the crop.

Again, the great differences in yield in passing from one type of soil to another, or even in some instances on the same type, cannot be altered by manuring. The Cecil clay in North Carolina yields 8 bushels of wheat, and the same soil in Maryland yields 25 to 30 bushels; by no scheme of manuring can the 8 bushels be much increased. By efficient cultivation, however, some North Carolina soils will give 25 bushels, but here the physical condition of the soil is altered. We are, in fact, back to Jethro Tull's position, that the farmer's business is to cultivate and not manure. Professor Whitney informs me that he is now taking up the question of soil management.

These are Whitney and Cameron's arguments, as far as I understand them. Two or three matters may be discussed.

The idea of regarding soil moisture as a culture solution is a very interesting one and is capable of considerable development. Pfeffer[1] is quoted to show that there is no evidence for the old theory that cultivated plants excrete acids (except carbonic acid) from their roots to dissolve mineral matter; and in fact the assumption is both cumbersome and unnecessary, all the phenomena being explained more easily without it. If the solution can be renewed in the soil quickly enough, it obviously suffices for plant growth. Renewal, then, becomes an important factor, it is partly brought about by the molar stream caused by transpiration, partly by the molar stream produced by

[1] *Physiology of Plants*, Eng. ed. Vol. I. p. 171, 1900.

capillary movement, and partly by the diffusion stream of salts towards the roots depending on the osmotic pressure gradient between the layers in contact with the roots and those further off. Assuming Briggs' figures to be correct it is evident that the quantities of potassium, calcium, and phosphoric acid delivered to the roots in the transpiration stream, would, even if completely taken up, only be a small proportion of what the plant actually absorbs; moreover, the mineral matter is mostly absorbed in the early stages of the plant's life and transpiration is most rapid when the leaf surface is most fully developed. The tendency of surface cultivation, by checking evaporation, would seem to be to decrease the amount of capillary movement. If the above reasoning is sound the main source of mineral matter must be looked for in the diffusion stream.

It is not at once obvious that this can be of great moment. The Rothamsted grass plots have been annually dressed for 50 years with large quantities of soluble substances and their herbage altered in consequence, but the effect stops at the edge of the plot and there is a sharp change in passing from one to another. Vertical movements, due to molar currents, can be traced, but lateral movement produced by diffusion through appreciable distances seems almost non-existent even after 50 years. On the other hand it is highly probable that diffusion goes on fairly rapidly through the molecular distances of capillary films provided the gradient is sharp enough, and this can be secured by having a reserve of readily soluble matter in the soil particles. The substance may be either dissolved, or temporarily "forced back" out of solution, the point is that it can readily redissolve as soon as the partial pressure of the particular ions decreases, and it is there whenever it is wanted.

Whitney and Cameron appear to overlook this entirely, but I think it would be agreed that soil solutions must be regarded dynamically, and not statically. The equilibrium ultimately attained is of minor importance compared with the ease with which equilibrium can be reestablished after a slight disturbance. The plant only has a relatively short space of time to take up the greater portion of its mineral matter, and even then there are checks and delays; unless the amount removed from the moisture near the roots can be rapidly replaced so that every favourable opportunity for growth may be seized we cannot expect the plant to do well. It is of purely academic interest to know that if there were time enough the soil would furnish sufficient nourishment.

The authors assume—and the assumption is a necessary part of their argument—that plant growth is independent of the concentration of the culture solutions. In a later bulletin they show that this is true of transpiration and argue that it must therefore be true for growth. We doubt, however, whether a plant physiologist would agree to this. There may be a certain parallelism between the effect of varying conditions on transpiration and on assimilation, but there are also sharp differences, and it is not safe to take one as a measure of the other. The two phenomena are not causally connected, and on a point of vital importance like this we should have preferred direct and unexceptionable proof. There is no necessary connexion even between transpiration and absorption of mineral matter. The indirect evidence adduced in the present bulletin seems to me to go quite against their case. "In water culture experiments the proportion of solid matters is usually maintained at between 0·5 and 2 parts in a thousand of water (*i.e.* 500 to 2000 parts per million), and no observations have indicated any material difference in the yield within these limits, although above *or below* these concentrations crops may suffer." (The italics are mine.) It seems to me that the crux of the question lies in the words "or below," for the solutions Briggs obtained from soils contained much less than 0·5 parts of dissolved matter per thousand.

The effect of varying amounts of carbon dioxide, heat, and illumination on assimilation has recently been carefully examined, and in all cases a small increase in any of these quantities causes increased assimilation up to a certain point, when these small increases have little or no effect, finally further increases are detrimental to assimilation. The effect of dissolved mineral matter has perhaps not been so carefully investigated, but the presumption is that it would behave in the same way, at any rate we should want very cogent proofs to convince us that it did not. Practical experience is that successive additions of mixed soluble salts of nitrogen, potassium, and phosphoric acid at first increase the crop, then the return diminishes, finally excessive amounts are injurious.

Whitney and Cameron do not deny that fertilisers increase the crop. They argue from Nernst's law that the addition of a potassium salt cannot permanently increase the concentration of potassium ions in the soil moisture, but they are surely wrong here. If there were 100 potassium ions in a given volume of a saturated solution to begin with and 100 more were added, it follows from Nernst's law that there may be precipitation and less than 200 will then be left in solution,

perhaps about 170, but not as few as 100. One of the leading American chemists, Noyes, has made a quantitative examination of the law and his results are very interesting in this connexion.

What is the function of a fertiliser? Whitney and Cameron say they do not know. Having dismissed, on altogether inadequate grounds as we think, its function as plant food, various other possibilities are suggested, but decision is reserved till further work has been done.

The bulletin is somewhat difficult reading, because it is at times hard to reconcile statements occurring on different pages, and a number of debateable side issues are introduced. But if we strip off the parts which appear to be inconsistent or non-essential we arrive at the following main idea:—

> Of the various factors influencing the yield of crops, the addition of mineral substances for plant food is only of minor importance

Our English idea is:—

> Other factors remaining constant, addition of mineral substances for plant food will increase the yield of crops.

These views are not incompatible with one another; we do not, unfortunately, make any experiments on cultivation or soil management, but we know it is extremely important, as are also the other factors, season, type of soil, etc.

In their latest bulletin[1] Whitney and Cameron aim at tracing the unknown physical factor which, in their opinion, controls the yield on an ordinary farm, but without success. Neither the movement of water in the soil, nor the rate of evaporation, nor the amount of water a soil will give up to seeds showed any connexion with fertility in the cases examined.

They begin, too, to study variations within the type. Instances of this are familiar enough to us in England: cases occasionally arise, in fact, where soils of the same formation with approximately the same chemical composition and physical structure show considerable differences in crop production. Whitney and Cameron selected two Cecil clays of very different productiveness but of identical chemical and physical constitution, they prepared aqueous extracts and used these as culture solutions for wheat seedlings. The extracts contained in parts per million:—

[1] "Investigations in Soil Fertility," Whitney and Cameron, *Bull.* No. 23, 1904.

	NO_3	PO_4	K	Ca
Good soil ...	3·2	1·6	3·6	3·2
Poor soil ...	3·5	1·6	2·0	2·8

and they were both neutral. Yet in spite of their identity as shown by analysis they gave very different results. The seedlings in the "good soil" extract had decidedly larger and healthier roots and a somewhat better development of leaves. 'More rigorous transpiration had taken place, 16 plants had in 30 days transpired 277·1 grams of water from the good soil extract and 171·7 from the poor soil. They then transferred the plants from the good to the poor extract and transpiration and growth were at once checked. On the other hand the plants moved from the poor to the good extract showed distinct improvement.

Similar results were obtained with a good and a bad Leonardtown loam; a photograph of the plants, taken from this bulletin, is reproduced here by kind permission of Professor Whitney.

Whilst, then, the differences observed in soils in passing from type to type can often be correlated with the physical structure the variations within the type cannot, for they extend also to the soil extracts. Further investigation of this question will constitute a very pretty chemical problem.

Work on Soil Physics.

Although not properly coming within the scope of this review, it is impossible to pass over the work of Briggs, King, and others, owing to its intimate connexion with soil fertility.

The method of mechanical analysis adopted is described in Bulletin 24 (1904)[1]. In principle it is the sedimentation method of Osborne and Knop, but the process is hastened by centrifugal action. Instead of adopting Schloesing's modification as we do, and breaking up the soil aggregates by a preliminary treatment with acid, they shake the soil in a motor-driven shaker with water containing a little ammonia. This treatment is considered sufficient to reduce the soil to its ultimate

[1] "The Centrifugal Method of Mechanical Soil Analysis," by L. J. Briggs, F. O. Martin, and J. R. Pearce.

particles. The difficulty with mechanical analysis is of course to represent the results in some simple way so as to facilitate comparison between one set of figures and another; a method is promised for a future bulletin.

The connexion between mechanical composition and physical properties is being carefully examined. Briggs[1] in 1897 applied certain dynamical principles to the movements of water in soil and found that they were related to, and could in a general way be deduced from, the structure of the soil as determined by mechanical analysis. But this is not quite true of the movements of dissolved salts; to some extent they follow the movements of the soil water, but not altogether. Thus King, in some papers published last year, found that there is a tendency for the ions Ca, NO_3, Cl, SO_4 to work upwards and accumulate in the surface soil, K ions show this to a much less extent, and the ions HCO_3, SiO_3, and PO_4 scarcely show it at all.

The problem is of obvious importance in its relation to soil management.

A very important subject is seriously attacked for the first time in Bulletin No. 25[2]. Buckingham investigates from a mathematical standpoint the effect of a difference of pressure on the rate at which air penetrates by transpiration into the soil, and then proceeds to actual measurements of the rates of diffusion and transpiration. The results show when the soil is still and the air has no lateral motion (like the movement of wind), *i.e.* when the driving force is simply a change in barometric pressure, the effects of transpiration are small compared with those produced by diffusion. The rate of diffusion was empirically found to be proportional to the square of the pore space[3] (*i.e.* the space not filled by soil or water) and is to a great extent independent of the texture of the soil.

ALKALI SOILS.

No notice of American work would be complete without a reference to this great question, which turns up also in some of our Colonies and dependencies. The general features of the problem are well known. Owing to the slight rainfall, the soluble matters always being formed

[1] "The Mechanics of Soil Moisture," by L. J. Briggs, *Bull.* No. 10.

[2] "Contributions to our knowledge of the Aëration of Soils," E. Buckingham, 1904.

[3] Buckingham calls it the "porosity," but it is a pity to use an abstract noun for a concrete quantity with which the useful expression "pore space" has for some time been associated.

in the soil are not washed away but remain; if much evaporation takes place the soil moisture in the surface layers becomes so concentrated that growth is impossible, and the land first of all runs to weeds and finally becomes a desert. There are two special cases, the salts may be harmless in themselves but injurious because of their excess, or the salts may be actually poisonous. In the first case the salts are usually sodium and magnesium chlorides and sulphates, and are generally spoken of as white alkali, of which plants can tolerate about 15,000 lbs. per acre in the first foot, corresponding to about ·45 °/₀ of the air-dried soil.

In the second case the dangerous salt is sodium carbonate; it decomposes the plant roots and other organic matter that may be present, forming black products, hence its name black alkali. Only small quantities are tolerated by plants. Hilgard showed that addition of sufficient calcium sulphate converted the sodium carbonate into sodium sulphate. The subsequent treatment then becomes the same as for the first case. Addition of calcium salts has the further effect of enabling the plant to tolerate more dissolved matter.

Two methods of attack have been developed. One is to investigate the way in which the salts are formed and to map out their movements in the soil. Means can then be devised, now that the laws of soil physics are fairly well known, to regulate these movements and keep the salts below the root range of the plant. The ordinary crops of the district can then be grown.

The second method is to frankly accept the situation and seek plants like the Australian salt bush, which will tolerate large quantities of mineral matter. This is only a *dernier ressort*, adopted when there is no prospect of the former succeeding.

The origin of the soluble substances in any particular case is ascertained by studying the geology of the district. The interaction of the soluble substances is, however, somewhat remarkable, and one phase of the question is discussed in Bulletins Nos. 17 and 18[1]. Setting out from Nernst's law it is shown that the solubility of a salt must increase when another salt containing no common ion is added, but decreases when the added salt contains a common ion. Thus addition of sodium chloride or magnesium chloride increases the solubility of calcium

[1] "Soil Solutions, their nature and functions and the classification of Alkali Lands," by F. K. Cameron, *Bull.* No. 17, 1901.

"Solution Studies of Salts occurring in Alkali Soils," by Cameron, Briggs, and Seidell, *Bull.* No. 18, 1901.

sulphate, whilst addition of calcium chloride decreases it, the ion calcium being common to both. The solubility in presence of sodium chloride at 23° is given in the following table:—

Grams of NaCl per litre added	Grams of $CaSO_4$ dissolved per litre
0·0	2·05
4·95	3·02
30 19	4·97
129·5	7·50

But when calcium chloride is present:-

Grams of $CaCl_2$ per litre added	Grams of $CaSO_4$ dissolved per litre
0 0	2·056
7·489	1·244
32·045	1·080
280·303	·203
367·850	·032

It follows that if a saturated solution of calcium sulphate is moving through the soil and comes in contact with a solution of calcium chloride, precipitation will occur and a bed of gypsum result, on the other hand if a solution of sodium chloride percolates through a soil containing gypsum it will take up far more of this than pure rain-water would do. As the rainfall in the alkali districts is only small and not regularly distributed—weeks may elapse without rain—irrigation is largely adopted. The water, being drawn from rivers, is never pure, and the interest of the foregoing investigation lies in the fact that it enables one to predict the effect of the water proposed for use on the soluble substances in the soil, effects which would otherwise be quite unexpected and might even be disastrous.

The determination of the soluble salts in the soil is rapidly made by the electrical method of Bulletins 8 and 15[1]. As the amount of soluble salt increases the conductivity also increases, and not only can comparative results be obtained, but, when the nature of the dissolved

[1] "An Electrical Method of determining the soluble Salt Content of Soils," Whitney and Means, *Bull.* No. 8, 1897; "Electrical Instruments for determining the moisture, temperature, and soluble Salt Content of Soils," Briggs, *Bull.* No. 15, 1899.

matter has been ascertained, its absolute amount can be measured more accurately than by extraction with water.

A good idea of the method of surveying an alkali district may be obtained by reading Bulletin 14[1]. The town of Billings, Montana, lies in a fertile valley originally showing no signs of "alkali." As, however, the annual rainfall is only about 13 inches it was necessary to irrigate, and then trouble from alkali set in. The district was thoroughly explored by T. H. Means, maps were drawn up showing the salt content of the soil, and the cause of the trouble discovered, all in about six weeks. It appeared that excessive amounts of irrigation water had been used, and that owing to the absence of underdrainage it could not get away, but had seeped through the land, dissolving the soluble sodium and calcium salts present and causing them to accumulate in the surface soil, where the solution became more concentrated by evaporation. The trouble was very pronounced in fields at a lower level. When the cause of the mischief had been located it was easy to suggest remedies. The farmers were instructed to use less water, to cultivate thoroughly so as to reduce evaporation, and to improve the drainage.

In other cases surface flooding and drainage have given remarkable results[2].

Alkali lands represent the upper limit of soluble matter in the soil possible for plant growth. This aspect of the question has been discussed jointly by a chemist and a plant physiologist in an excellent report issued by the Department of Agriculture[3].

Practical Applications.

The first impression of the practical man on reading these bulletins would be that they were too scientific and too little *ad hoc* to be of any possible utility, but that view is not held in America. Two special applications of the work of the Soil Bureau may be mentioned.

Observing that certain Connecticut soils had the same mechanical analysis as the high class tobacco soils of Sumatra, Whitney tried replacing the old Connecticut varieties by the more valuable Sumatra

[1] "The Alkali Soils of the Yellowstone Valley," Whitney and Means, *Bull.* No. 14, 1898.

[2] *Report* of the Secretary of Agriculture for 1904, p. 70.

[3] "Some Mutual Relations between Alkali Soils and Vegetation," Kearney and Cameron, *Report*, No. 71, 1902.

tobaccos[1]. To ensure favourable climatic conditions the whole field had to be covered with cheese cloth. Whitney introduces a delightfully human touch when he says, "there was a good deal of adverse criticism in the valley of the idea of attempting to change the character of the leaf, as the Connecticut Havanna seed had been grown there for upwards of 100 years." But the success of the experiment appealed to the practical man, and in spite of the great initial expense the cultivation of the new variety is being taken up.

Other instances could be quoted where important practical results have followed from the Survey. Yet the cost of this is little more than a farthing an acre.

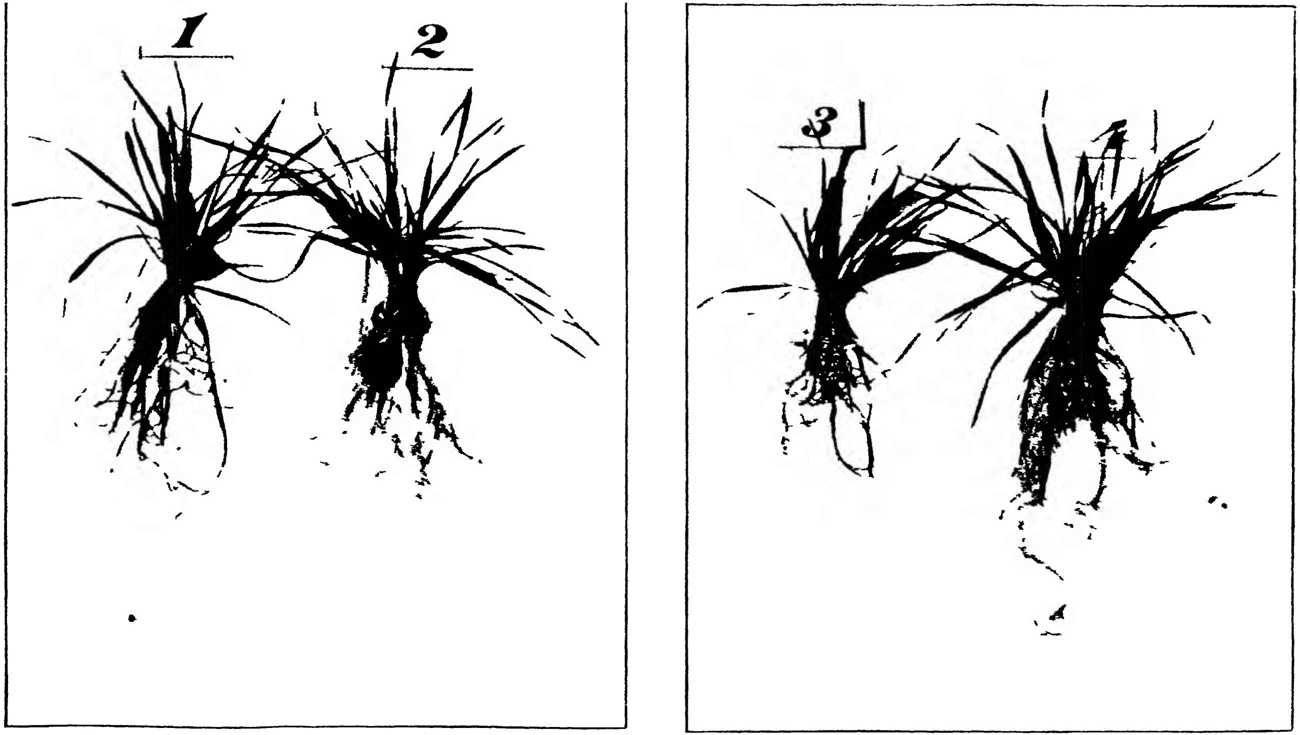
Probably no country has ever had to deal with a more serious agricultural question than alkali land, compared with which the problem of our own derelict lands is insignificant. The scientific aspects of the matter are being carefully attacked, and already sufficient is known to enable the Bureau to suggest methods of reclamation. The Secretary reports that much of the land is now so far improved that shallow rooting crops can grow and in some cases even the deep rooting lucerne—one of the American farmers' staple crops—flourishes. In one of the districts mentioned the land is said to have risen from a purely nominal value to $250 or $300 per acre, the total cost of reclamation being but a small fraction of this.

The United States Department of Agriculture furnishes us with a striking example of what can be done by a central staff whose sole business is to attack general questions, discover the underlying principles, and furnish the local colleges and experiment stations with methods of investigation, leaving to them the application to their particular conditions. No one will suppose that general scientific principles can be satisfactorily investigated at a college or station with multifarious activities and important local duties, and yet it is being recognised that these general scientific principles are of vital importance in agriculture. At any rate the Americans see this clearly enough, and the Report of the Secretary of Agriculture for 1904 is most convincing reading. A more optimistic report can scarcely be imagined; 1903 had been considered the most prosperous year on record for the farmer, but it was eclipsed by 1904. During the last five years the value of farm products has increased 42 °/₀, and the total value works out to nearly five thousand million dollars. The

[1] "Growing Sumatra Tobacco under shade in the Connecticut Valley," Whitney, *Bull.* No. 20, 1902.

Secretary measures this "unthinkable aggregate" by some comparisons, given with a profuseness and an exuberant enthusiasm engendered by years of increasing prosperity. Land has risen in value, the number of depositors and the amounts deposited in the banks of the Agricultural States have doubled or trebled during the last few years, and in other ways the increased well-being of the farmer is showing itself. This result is all the more striking when one remembers that on the whole the period has been one of some commercial depression.

In concluding this review I wish to thank Professor Whitney, Chief of the American Soil Bureau, who has kindly furnished me with a number of typical bulletins, and has given me other help.



Development of wheat seedlings in aqueous extract of soil:

1. From poor Cecil clay.
2. From good Cecil clay.
3. From poor Leonardtown loam.
4. From good Leonardtown loam.

A CONTRIBUTION TO THE STUDY OF FACTORS AFFECTING THE QUALITY AND COMPOSITION OF POTATOES.

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THE work was undertaken with the hope of establishing some connexion between the characters of soils as shown by chemical and mechanical analyses, and the quality and composition of the potatoes grown on them. As regards quality, most attention has been given to the occurrence of 'blackening' after cooking, especially after a second warming up, and an attempt has been made to get at the cause of this phenomenon. This defect has been often complained of by potato growers and dealers, and seriously affects the price of samples marketed for consumption in towns where the largest buyers are hotels and restaurants which demand a potato capable of keeping its colour after a second steaming. 'Blackening' is often associated with sandy soils heavily manured with farmyard dung or town manure, and it has been observed in tubers grown with spring dressings of kainite; concordant opinions, however, are not to be had from practical men, and in fact the defect may arise on the most widely different types of soil. In order to exclude disturbances due to variety, 'Up to Date,' as one of the most widely grown sorts, has alone been investigated.

SOILS AND POTATO SAMPLES OF THE SEASON 1903.

During the summer of 1903 samples were taken of soil and subsoil from two soils in the neighbourhood of Dunbar, one, at North Belton, from a field which produces potatoes showing a tendency to blacken, and the other at Thornton Loch, from land that can be depended on for a good quality crop. Soil and subsoil were each sampled to a depth of 9 inches. In the autumn samples of potatoes from these soils were kindly forwarded by Mr J. D. Bowe, Dunbar, by whom the soils in

question had been pointed out. Both soils are of 'drift' origin but preserve the character of the underlying Old Red Sandstone rock.

During the autumn a visit was made to Boston, Lincs., and samples of soil and subsoil were taken from two fields on the farms of Mr J. H. Dennis, to whom I am indebted for help and information. Samples of potatoes just raised from these soils were also secured. The soil designated 'warp A' had only recently been reclaimed, and was carrying its first crop of potatoes. It is separated from the sea by a marsh several miles wide. The 'warp B' soil lies two miles further inland and has been under cultivation for a much longer time. Both soils are of natural formation, and have not been produced by artificially regulated deposit like those of the Humber district. Oats preceded the potato crop on both soils, and the latter received a dressing of about 12 tons of farmyard manure, and an artificial mixture containing 5—6 p.c. ammonia, 20—25 p.c. phosphates, and 5—6 p.c. potash at the rate of 6 cwt. to the acre. Two samples of potatoes were obtained from 'warp A' field, one from a portion where the growth had been normal, and the other from a part where the haulm had died off prematurely owing to disease.

A sample of potatoes was obtained from the Royal Agricultural Society's experimental farm at Woburn, grown on soil of which a mechanical analysis had been made at the Rothamsted Laboratory.

Cooking Test.

The potatoes peeled and unpeeled were steamed under atmospheric pressure for one hour, allowed to get quite cold and again steamed for half-an-hour, and after cooling broken into halves either across or lengthwise. Some were cooked by boiling in water, and after cooling were given a steaming for half-an-hour. The results are arranged in the order of quality.

1. Thornton Loch. Good colour. No 'blackening' at heel end.
2. Woburn. „ Slight „ „ „
3. Warp B. Stronger. Darkening at heel end.
4. North Belton. Blackened at heel end.
5. Warp A (mature) } Very white and waxy and much
6. „ A (immature) } blackened in cortex and at heel end.

In no case was the 'blackening' very marked, and with the exception of the samples from 'warp A' was confined to the heel third of the tuber, being most evident near the scar marking the place of attach-

ment to the rhizome. In the case of the 'warp A' samples the blue-black discolouration extended up the cortex towards the seed end. The appearance was least marked in the potatoes which were boiled, and those cooked in the skins were always more 'blackened' than the peeled tubers with similar treatment.

Mechanical Analyses of Soils.

The method employed was that described by Hall[1], and the calcium carbonate determinations were made with the apparatus devised by Hall and Russell[2]. The results are set out in Table I., the stones and calcium carbonate being calculated on the air-dry material.

It is evident that all the soils fall within the categories of 'sand' and 'sandy loam' in virtue of the high proportion of grit and sand particles, and the low amounts of 'Klay.' The Thornton Loch soil and subsoil show a very even distribution of all grades, the fractions ensuring porosity being well balanced by an adequate supply of the finer particles which give retentiveness.

The North Belton soil, on the other hand, is rather short of the finest fractions. The 'warp A' soil shows a very unusual composition with its very high percentage of 'sand,' absence of grit and stones, and extremely low amounts of fine silt and 'Klay.' The 'warp B' soil is better balanced with a higher 'Klay' content, but is also lacking in 'grit' and stones to counteract a tendency to 'run' and set. The best potatoes (see 'cooking test') are from the light soils with the most 'Klay,' Thornton Loch with its model composition standing first, and the bad cookers from the soils deficient in the finest particles.

Chemical Analyses of Soils.

These are given in Table II. The citric acid soluble potash and phosphoric acid were determined by Dyer's method[3]. 'Soluble humus' was determined in 5 grams of soil rubbed up with dilute acid and allowed to stand 1 hour, thrown on a large Buchner filter, washed free from acid and treated with ammonia, using the filter pump (1 part strong ammonia and 1 part water) till the filtrate came away colourless. The dark liquid was evaporated and dried at 100° C. and weighed, and after ignition again weighed, the difference being set down as 'soluble humus.'

[1] A. D. Hall, *The Soil*, 1901, p. 48. *Trans. Chem. Soc.*, 1904, Vol. LXXXV. p. 950.

[2] *Trans. Chem. Soc.*, Vol. LXXXI. p. 81, 1902.

[3] B. Dyer, *Journ. Chem. Soc.*, 1894, Vol. LXV. p. 115.

TABLE I. Mechanical analyses of soils.

	Stackyard Field, Woburn		North Belton, Dunbar		Thornton Loch, Dunbar		'Warp A,' Boston		'Warp B,' Boston	
	Soil	Subsoil	Soil	Subsoil	Soil	Subsoil	Soil	Subsoil	Soil	Subsoil
Stones, over 3 mm. (determined on entire sample)	0·00	0·00	11·37	12·66	9·65	5·41	0·11	0·00	0·00	0·00
Moisture dissolved by acid ...	1·83	2·26	4·30	3·27	3·14	3·00	4·40	5·56	3·23	3·52
Loss on ignition	3·84	2·70	6·92	5·70	6·16	4·78	6·95	6·16	6·35	5·35
Calcium carbonate..............	—	—	0·15	under 0·10	0·31	0·19	0·90	3·78	under 0·10	under 0·10
Fine gravel, 3—1 mm.	1·01	1·02	3·00	4·14	0·99	0·88	0·00	0·00	0·00	0·00
Grit, 1—·2 mm.	49·91	50·12	33·80	36·79	23·66	21·70	0·23	0·19	0·11	0·10
1st sediment, ·2—·04	16·11	15·85	28·00	26·07	38·18	35·60	65·72	66·13	53·58	53·04
2nd ,, ·04—·01	11·05	12·52	5·55	5·44	6·81	8·75	9·89	8·82	12·32	11·00
3rd ,, ·01—·004	3·50	3·89	8·40	4·58	5·86	7·08	8·40	5·85	7·89	7·83
4th ,, ·004—·002	2·06	2·05	2·40	3·84	5·94	3·56	1·91	3·57	2·43	2·70
'Klay,' ·002 and less......... .	9·68	8·56	6·56	9·52	9·48	14·82	2·64	3·70	14·66	16·58
Total (excluding stones and calcium carbonate)	98·99	98·97	98·93	99·35	100·22	100·17	100·14	99·98	100·57	100·12

TABLE II. Chemical analyses of soils.

	North Belton, Dunbar		Thornton Loch, Dunbar		'Warp A,' Boston		'Warp B,' Boston	
	Soil	Subsoil	Soil	Subsoil	Soil	Subsoil	Soil	Subsoil
Water..................	1·72	2·23	1·08	2·06	1·85	1·72	2·06	2·23
Loss on ignition	6·92	5·70	6·16	4·78	6·95	6·16	6·35	5·35
Nitrogen	·171	·139	·162	·087	·223	·116	·184	·134
Potash, K_2O	·286	·329	·460	·527	·532	·494	·629	·645
Citric sol. K_2O	·01	—	·023	—	·04	—	·017	—
Phosphoric Acid, P_2O_5 .	·16	·129	·120	·042	·125	·103	·189	·136
Citric sol. P_2O_5.......	·034	—	·022	—	·024	—	·034	—
Calcium carbonate, $CaCO_3$	·150	under ·10	·314	·187	·902	3·780	·08	under ·10
Lime, CaO.................. .	·88	·71	·90	·70	1·175	2·50	·62	
Magnesia, MgO	·66	·63	·65	·69	·74			
Ferric oxide, Fe_2O_3	4·74	4·18	5·50	3·40	3·10	3·10	3·60	4·15
Manganese oxide, Mn_2O_3...	·21	·13	·15	·14	·10	?	·14	·15
Insoluble residue	84·35	84·22	85·18	85·40	85·11	82·88	83·91	83·00
Soluble humus...............	·90	·70	·62	·52	·88	·32	·80	·58

All the soils show high nitrogen figures, and so also do the warp subsoils. The total potash is correlated with the amount of 'Klay,' and is very low in the North Belton soil. The 'citric acid soluble' potash is very low in North Belton and 'warp B' soils, and is probably below the limit of safety for a crop like potatoes. Phosphoric acid is lacking in none of the soils, and the citric acid figures indicate high availability throughout. Calcium carbonate is very deficient in both the North Belton and the 'warp B' soils. Ferric oxide, a high proportion of which is often said to accompany good quality potatoes, is about the same in all the soils.

The Thornton Loch soil shows no chemical weakness, but its neighbour North Belton is very short of available potash and calcium carbonate, defects which could very well account for the inferior quality of potatoes raised from it. On the other hand, the 'warp A' soil, yielding the worst potatoes, gives a very good chemical analysis.

ANALYSIS OF TUBERS.

The 'specific gravity' was determined on about 1000 grams of medium sized tubers by weighing in air and again in distilled water. Dry matter and starch were determined in the air-dry meal after rapid drying of the sliced material at 55° C. Starch was estimated by a method described[1], depending on the action of a malt extract of predetermined 'diastatic activity' upon starch paste for a fixed time at constant temperature. The malt, kindly sent from the Guinness Laboratory had a 'conversion factor' of 82, *i.e.* by acting for 1 hour at 57° C. on a starch paste, 82 parts of maltose were formed for every 100 original parts of starch. The 'cupric reduction' of the resulting product was determined directly and calculated for maltose.

The results are given in Table III.

TABLE III.

Origin of potatoes	Specific gravity	Dry matter per cent.	Starch per cent.	
			in dry matter	in fresh substance
North Belton	1·0944	23·31	81 6	19·02
Thornton Loch	1·0899	21·85	78·0	17·04
Woburn	1·0858	20·99	79·1	16·60
Warp A, immature	1·0750	18·93	68·0	12·87
Warp A, mature	1·0810	20·15	70·17	14·14
Warp B	1·0870	21·30	74·8	15·93

[1] *Trans. Guinness Laboratory*, Vol. I. No. 1.

The specific gravity, and dry matter, do not appear to show much relation to quality, although the three best lots stand near together. The low proportion of starch in the dry matter of potatoes from both 'warp' soils is worthy of note.

The nitrogen determinations were made on the fresh unsprouted material. A dozen average sized tubers were rasped down as fine as possible, well mixed, and portions withdrawn at once for the various estimations. The figures for the proteid nitrogen were obtained by adding the 'insoluble' nitrogen to that contained in the precipitate formed by boiling the filtrate for three minutes with a few drops of 5 per cent. acetic acid. The results are shown in Table IV. It will be observed that, on the whole, a low proportion of total nitrogen and a high proportion of non-proteid nitrogen accompany good quality. This is well shown by comparing the figures for the good quality potatoes from Thornton Loch and Woburn, with those for the two bad samples from 'warp A.'

TABLE IV.

Nitrogen determined in fresh tubers.

	North Belton	Thornton Loch	Warp A, immature	Warp A, mature	Warp B	Woburn
(*a*) Per cent. in dry matter						
Total	1·04	1·28	1·42	1·55	1·44	1·25
Insoluble	0·23	0·24	0·22	0·33	0·27	0·18
Precipitated by acetic acid...	0·25	0·26	0·52	0·62	0·33	0·33
Proteid	0·48	0·50	0·74	0·95	0·60	0·51
Non-proteid	0·56	0·78	0·68	0·60	0·84	0·74
(*b*) Per cent. in fresh substance						
Total	·237	·270	·270	·315	·301	·261
Proteid	·109	·107	·140	·191	·125	·104
Non-proteid	·128	·163	·130	·124	·176	·157
(*c*) Distribution of Nitrogen in parts per hundred of total Nitrogen						
Insoluble	21·94	18·88	15·19	21·58	18·27	14·18
Acetic acid precipitate	24·05	20·74	36·66	39·68	23·22	25·67
Proteid	45·99	39·62	51·85	61·26	41·49	39·85
Non-proteid	54·01	60·38	48·15	38·74	58·51	60·15

The results for the ash analyses are given in Table V.

The low amount of potash in the North Belton ash corresponds to a deficiency in the soil.

The high chlorine figures for the ash of the three bad samples stands in harmony with the often observed bad quality of potatoes manured with large dressings of chloride of potash or kainite.

Table V.

Ash of potatoes.

Pure ash—parts per hundred of dry matter.

Constituents—parts per hundred of pure ash.

Origin	Pure ash	Potash	Phosphoric acid	Lime	Magnesia	Chlorine	Ferric oxide
North Belton . .	3·28	53·84	11·60	1·28	3·25	6·42	·43
Thornton Loch ...	3·97	56·32	9·70	1·04	3·52	2·57	·25
Warp A, immature	5·36	56·35	10·86	1·05	3 37	6·15	·43
Warp A, mature . .	4·65	57·24	10·74	1·16	2·77	4·47	·49
Warp B	3·70	57·60	13·29	1·24	3·71	1·65	·46
Woburn	4·31	58·61	14·80	1·48	2·61	2·97	·20

Potato Samples of the season 1904.

The season 1904 was in marked contrast to that of 1903. The latter with its cold wet summer and autumn was in every way abnormal, and disease was very widespread. The summer of 1904 was normal as regards rainfall and temperature, but owing to favourable vegetative conditions in late summer and autumn there was a good deal of 'second growth.'

Advantage was taken of the National Potato Society's variety trials at various centres, to secure samples of 'Up to Date' potatoes from seventeen localities.

The samples were subjected to a 'cooking test' of quality, the result of which, together with soil characteristics, is set out in Table VI. The samples are divided into three sets according to whether the 'blackening' was insignificant, moderate, or very marked. As in the 1903 samples discolouration was confined to the heel end of the tuber, and was most noticeable near the base.

TABLE VI.

Cooking test of potatoes from the crop of 1904.

Locality	Behaviour	Soil
	A. 'Blackening' insignificant	
1. Reading College	No blackening in any part	Sandy soil on red gravel
2. Wallingford, Bucks....	Very slight darkening at heel end in individual tubers	....
3. Long Ashton, Somrst.		....
4. Warwick................		Medium loam with gravel
5. Chelmsford		Heavy loam
	B. Moderate 'blackening'	
6. Edmonton, Middlesex...	....	....
7. Cockle Park, Northumberland	....	Medium loam on mixed clay and sandstone
8. Wye College, Kent	....	....
9. Merton, Surrey...........	....	Sandy brash
10. Orton, Wolverhampton	....	Medium sandy loam
	C. Marked 'blackening'	
11. Holmes Chapel, Cheshr.	Badly discoloured, especially those steamed in skins	Moderately heavy loam
12. Halesowen, Stafford ...	,, and diseased	Stiff loam on clay loam
13. Droitwich	,, and some diseased	Sandy loam on New Red Sandstone
14. Evesham	,, more diseased	Clay loam on loamy clay
15. Kilnswick	,, badly diseased	Marly loam on marl
16. Creswell, Stoke..	,, ,, ,,	Medium loam on clay
17. Bath	Showed blackening worse than any other	Clay loam manured in part with ashes

EXPERIMENTS ON THE NATURE OF THE COLOURING MATTER.

It was observed that the freshly rasped material showed the same rapidity of surface change to red, brown and finally black, from both heel and seed halves of 'blackening' tubers and it was not less rapid from the best samples.

This excludes any connexion between 'blackening' and the action of the tyrosin splitting oxydase which causes the discolouration of the raw juice. That the discolouration is not due to physical causes was proved by drying and grinding a steamed piece of blackened tuber and comparing the hue of the powder with that from a similarly treated piece of normal colour. The powder from the blackened portion was grey in contrast with the creamy white of the other.

In the belief that the 'blackening' might be due to an oxidation of tannin derived from the splitting up of a glucoside during cooking,

TABLE VII. Dry matter and distribution of nitrogen determined on fresh material.

	Holmes Chapel, bad quality		Evesham, bad quality		Bath, bad quality		Reading, good quality		Cockle Park, good quality		Warwick, good quality	
	heel end	seed end	heel end	seed end	heel end	seed end	heel end	seed end	heel end	seed end	heel end	seed end
Dry matter	22·75	22·12	23·87	22·37	19·17	18·94	23·65	21·79	24·05	22·18	25·45	24·06
Nitrogen in parts per hundred of fresh substance:												
Total Nitrogen	·356	·336	·275	·276	·257	·265	·283	·268	·305	·285	·335	·310
Proteid Nitrogen	·162	·168	·132	·135	·120	·122	·118	·119	·130	·119	·135	·134
Non-proteid Nitrogen	·194	·168	·143	·141	·137	·143	·165	·149	·175	·166	·200	·176
Nitrogen in parts per hundred of dry matter:												
Total Nitrogen	1·565	1·519	1·152	1·190	1·341	1·399	1·196	1·230	1·268	1·285	1·316	1·288
Proteid Nitrogen	·712	·759	·553	·603	·626	·644	·499	·546	·540	·536	·530	·557
Non-proteid Nitrogen	·853	·760	·599	·587	·715	·755	·697	·684	·728	·749	·786	·731
Proteid Nitrogen in parts per hundred of total Nitrogen	45·5	50·0	48·0	48·9	46·7	46·2	41·8	44·4	42·6	41·9	40·3	43·2
Non-proteid Nitrogen in parts per hundred of total Nitrogen	54·5	50·0	52·0	51·1	53·3	53·8	58·2	55·6	57·4	58·1	59·7	56·8

Average distribution of nitrogen and dry matter in three bad and three good samples.

	Holmes Chapel, Evesham, Bath, bad quality		Reading, Cockle Park, Warwick, good quality	
	heel end	seed end	heel end	seed end
Dry matter	21·93	21·14	24·38	22·68
Nitrogen in parts per hundred of fresh substance:				
Total Nitrogen	·296	·292	·308	·288
Proteid Nitrogen	·138	·142	·128	·124
Non-proteid Nitrogen	·158	·150	·180	·164
Nitrogen in parts per hundred of dry matter:				
Total Nitrogen	1·353	1·369	1·260	1·268
Proteid Nitrogen	·630	·669	·523	·546
Non-proteid Nitrogen	·723	·700	·737	·722
Proteid Nitrogen in parts per hundred of total Nitrogen	46·7	48·4	41·6	43·2
Non-proteid Nitrogen in parts per hundred of total Nitrogen	53·3	51·6	58·4	56·8

some determinations of tannin were made both on air-dry and fresh materials. The material was thoroughly extracted either with cold water or hot alcohol, and the tannin determined by the indigo-permanganate-hide powder method. The amount found varied from ·04 to ·05 per cent. of the dry matter, and showed no difference in heel and seed end of 'blackening' samples. As no sample hitherto examined has shown really strong discolouration, no further attempt could be made to separate a colouring matter present in such infinitesimal quantity.

NITROGEN DETERMINATIONS.

In order to observe whether 'blackening' stood in any relation to the distribution of nitrogen in heel and seed end, determinations were made on the transverse halves of tubers from six samples. Three samples (Reading, Cockle Park, and Warwick) which cooked well were compared with three (Holmes Chapel, Evesham, and Bath) which discoloured badly. The results are shown in Table VII.

The figures do not indicate that the distribution of nitrogen in the two ends of 'blackening' samples differs from the relation found in good cooking samples. The dry matter determinations show a consistently greater amount in the heel end over the seed end, indicating a higher proportion of starch near the base of the potato.

The proportion of nitrogen and the ratio of proteid to non-proteid is much the same as in the 1903 samples.

The good samples, as in 1903, show a lower total nitrogen in dry

TABLE VIII.

Average results for dry matter, and nitrogen in dry matter for best and worst samples of two seasons.

	Six bad samples: North Belton, Warp A immature, Warp A mature, Holmes Chapel, Evesham, Bath	Six good samples: Thornton Loch, Woburn, Warp B, Reading College, Cockle Park, Warwick
Dry matter	21·16	22·46
Total Nitrogen	1·348	1·293
Proteid Nitrogen	·686	·535
Non-proteid Nitrogen	·662	·758
Proteid Nitrogen in parts per hundred of total Nitrogen	50·9	41·4
Non-proteid Nitrogen in parts per hundred of total Nitrogen	49·1	58·6

matter and a higher proportion of non-proteid nitrogen as compared with the bad cookers.

In Table VIII. figures are given showing the average dry matter and nitrogen in dry matter for the good and bad samples of both years. These results show a higher dry matter and lower total nitrogen in the good quality potatoes, and in a very marked manner, high non-proteid nitrogen and correspondingly low proteid nitrogen.

CONCLUSIONS.

The high ratio of amide to proteid nitrogen in the good quality potatoes examined is a point of much interest, but will require to be confirmed by many more analyses before being regarded as a general characteristic of good quality tubers. The uniformly higher proportion of dry matter in the heel halves of all the samples indicates that the basal end of the tuber is richer in starch than the seed end, although this relation may not hold for material which has started to sprout.

Indications seem to point to physical causes as exercising the greatest influence on quality, especially such as determine temperature and water supply. The mechanical analyses of the soils, for instance, show that the best potatoes came from soils which were neither lacking in the coarse particles (gravel, grit, and coarse sand) which ensure porosity and consequently warmth, nor in the finest materials (fine silt and 'Klay') which secure retention of water.

Climate, as affecting the distribution of seasonal rainfall and air temperature, must always play an important part in modifying the value of a soil for raising good quality potatoes, so that although a light soil of good physical composition (*e.g.* Thornton Loch) produces the best quality tubers in a moist climate, a heavy soil may do better in a warm dry climate. It is proposed to continue the work along lines suggested by the foregoing considerations, making use of pot experiments with regulated conditions of temperature and water supply in soils of varying texture.

As previously mentioned no sample as yet examined has shown really strong 'blackening,' so that nothing conclusive as regards that aspect of quality has been arrived at.

The investigation is being carried out at the Laboratory of the Lawes Agricultural Trust, to whom my best thanks are due, for the use of the laboratory and apparatus. I must express my sense of deep obligation to Mr A. D. Hall, M.A., Director of the Rothamsted Experimental Station, who suggested the investigation, and continued to give me valuable advice throughout.

NOTE ON THE FATE OF CALCIUM CYANAMIDE IN THE SOIL.

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THE experiments described below have been carried out to confirm some results obtained by F. Löhnis[1], who made it appear highly probable that soil bacteria were concerned in rendering calcium cyanamide assimilable for crops. It had been supposed that the reaction of calcium cyanamide in the soil was a purely chemical one[2]. The material used was taken from a supply of "Kalkstickstoff" received at the Rothamsted Experimental Station from the "Cyanid Gesellschaft" of Berlin early this year. Nitrogen determinations by the Kjeldahl method showed the crude fertiliser to contain 20·3 per cent. nitrogen, equal to 58 per cent. pure calcium cyanamide. In order to obtain the action of soil organisms on the cyanamide a culture solution of the following composition was prepared:—

"Kalkstickstoff"	1·0	gram.
Monopotassium phosphate	0·5	"
Cryst. magnesium sulphate	1·0	"
Sodium chloride	0·2	"
Dextrose	1·0	"
Distilled water	1	litre.

Erlenmeyer flasks of 250 c.c. capacity each received 75 c.c. of the solution and 1 gram of fresh soil taken from arable land at a depth of 10 cm. Five of these were placed in the incubator without further treatment, two others were boiled for three minutes to secure sterilisation, and another pair to which no soil was added were treated with a few drops of a concentrated corrosive sublimate solution before incubation.

[1] *Centralbl. f. Bakt.* Abt. II. Bd. 14, p. 87, 1905.

[2] See this vol., p. 146.

Two control solutions not previously boiled gave by distillation with magnesia a mean of ·70 mg. nitrogen, and another pair after boiling for three minutes yielded by distillation a mean of 1·2 mgs. nitrogen. The total nitrogen found by Kjeldahl's method was 15·0 mgs. in 75 c.c. solution and 1·4 mgs. in 1 gram of the soil. The flasks were incubated at 25° C. for 43 days, and were then examined for ammonia and total nitrogen. The two solutions inoculated with soil and boiled developed a surface film after a few days, and can consequently only be regarded as partially sterilised. The results of a qualitative examination are given in Table I.

TABLE I.

Incubation period at 25°: March 15—April 27, 43 days.
Iridescent surface film and deposit in all flasks seeded with soil.
Flasks containing corrosive sublimate showed no growth.
No solution showed either nitrite or nitrate.

Culture	Ammonia by Nessler	Reaction
1. Not boiled............	abundant	strongly alkaline
2. ,, ...	faint	weakly alkaline
3. ,, ...	abundant	strongly alkaline
4. ,, ...	moderate	less strongly alkaline
5. ,, ...	faint	moderately alkaline
6. Partly sterilised ...	,,	weakly alkaline
7. ,, ...	,,	,, ,,
8. Corrosive sublimate	none	neutral
9. ,, ,,	,,	,,

The results of the determinations of ammonia by distillation with magnesia and of the nitrogen in the residue therefrom by Kjeldahl's method are shown in Table II.

Culture (5) was not distilled but was tested for sugar with Fehling's solution, and gave a negative result. It is evident that the alkalinity of all the incubated solutions was due to free ammonia, so that it is not surprising that a considerable loss of nitrogen by volatilisation took place. In the solutions to which corrosive sublimate had been added there was practically no formation of ammonia, indicating that a sterile calcium cyanamide solution can be kept for a long time without any notable reaction occurring with the water present. It is reasonable to infer from this, that the formation of ammonia from cyanamide in the soil can be due in only a very minor degree to a purely chemical process. On the other hand where soil organisms were active as much as 80 per cent. of cyanamide nitrogen was converted to ammonia.

TABLE II.

Solution	Nitrogen Magnesia distillation	Nitrogen Magnesia residue	Nitrogen, total found	Nitrogen originally present	Nitro[illegible] lost by eva[illegible]ation	Ni[illegible] [illegible]hanged to A[illegible]ia	
	mgs.	mgs.	mgs.	mgs.	mgs.	mgs.	per cent.
1. Not boiled......	7·40	4·19	11·59	$\left\{\begin{matrix}15{\cdot}0+1{\cdot}4 \\ \text{(soil)}\end{matrix}\right\}$	4·81	12·21 − ·70 = 11·51	80·5
2. "	1·82	lost	—	16·4			
3. "	7·26	5·59	12·85	16·4	3·55	10·11	70·7
4. "	4·47	10·06	14·53	16·4	1·87	5·64	40·0
6. Boiled, partly sterilised...	3·35	9·22	12·57	16·4	3·83	7·18 − 1·2 = 5·98	39·9
7. " ...	2·65	11·60	14·25	16·4	2·15	3·60	24·0
8. Corrosive sublimate sterilised	0·70	13·97	14·67	15·0	0·33	0·33	2·2
9. " ...	0·70	14·04	14·74	15·0	0·26	0·26	1·7

Löhnis in a further communication[1] has shown that two organisms (B. Kirchneri and B. lipsiense), isolated by him from cyanamide solutions seeded with soil, can ammonify that fertiliser very rapidly. They act very feebly on urea and peptone, while the bacteria which rapidly ammonify urea and peptone show little or no power to attack calcium cyanamide.

It may be remarked in conclusion that calcium cyanamide $CaCN_2$ contained in "Kalkstickstoff" is insoluble in water but reacts with the latter to form a soluble salt and calcium hydrate which renders the freshly prepared solution alkaline:

$$2CaCN_2 + 2H_2O = CaH_2C_2N_4 + Ca(OH)_2.$$

The author was able, by precipitating all the lime with ammonium oxalate, evaporating the filtrate to dryness, extracting with a little strong alcohol and allowing the latter to evaporate at the ordinary temperature, to obtain yellow crystalline plates which yielded on analysis 62·70 per cent. nitrogen and agreed with the description given for dicyandiamide (Beilstein, *Organische Chemie*) which contains when quite pure 66·60 per cent. nitrogen. A solution of calcium cyanamide after long standing goes over into dicyandiamide which yields no ammonia by distillation with magnesia.

[1] *Centralbl. f. Bakt.* II. 14, p. 389.

THE BEARING OF MENDELISM ON THE SUSCEPTIBILITY OF WHEAT TO RUST.

By E. J. BUTLER, M.B., F.L.S.,

Cryptogamic Botanist to the Government of India.

In Mr Biffen's paper on "Mendel's Laws of Inheritance and Wheat Breeding" in the first number of this *Journal* reference is made on page 40 to the characters of immunity and susceptibility to the attacks of yellow rust. Mr Biffen's experiments confirm the conclusions of other observers, such as Farrer in Australia, that resistance and susceptibility to rust are inherited characters, and he shows that they follow the Mendelian laws. As the question is of enormous practical importance in the wheat growing countries this general statement requires to be made more precise. It holds for a given rust in a particular locality; it may or may not hold where the wheat is exposed to the attacks of a second species of rust or when it is transferred to another locality. Thus experience in India so far seems to show that resistance to yellow rust, *Puccinia glumarum*, does not imply resistance to orange rust, *P. triticina*. And it is certain that the characters alter with change of locality. Several of Farrer's hybrids resistant to Australian rusts have proved susceptible to the same rusts in India. On the other hand *Kathia* wheat, which is particularly liable to the attacks of all three Indian wheat rusts, has been recommended by Carleton for extended trial in the United States, having shown a promising degree of resistance to yellow rust there. A still more striking case is that of spelt wheat, which has proved very resistant in some parts of India and not in others. Therefore in the breeding of rust-resistant wheats the results of work in one locality should be accepted with caution in others as long as we do not know on what immunity depends. In spite of this it is impossible to exaggerate the practical value, for countries like India, where the extension of wheat cultivation is largely bound up

with the production of wheats possessing certain definite characters, such as resistance to rust, drought, &c., of the work already done in defining the lines on which wheat breeding must proceed in the future.

In the same section of his paper Mr Biffen concludes that his results are opposed to the assumption of a latent germ in the wheat grain, through which the disease is transmitted from season to season. For he found that the progeny of a cross were equally susceptible whether the male or female parent was the susceptible one, although the latent germ must necessarily arise from the female only. Though Eriksson's "mycoplasm" hypothesis requires establishment on a more solid basis than has been the case so far, still it is difficult to see how the results mentioned vitiate it. Were it the case that immunity depends on the absence of the latent germ from the grain, then Mr Biffen would probably be right. But there is an immunity dependent on the behaviour of the tissues of the leaf to infection by spores which should not be lost sight of. Mr Massee[1] and Mr Salmon[2] have shown how the resistance of a leaf may be overcome by appropriate chemical or physical treatment, and Professor Marshall Ward[3] that resistance to yellow rust is due to the reaction between the uredospores and the leaf-cells, and has nothing to do with the character of the grain. That susceptibility to rust means this liability to uredospore infection, and not a large proportion of germ-bearing grains is shown by the following experiment. A tent of thin cloth, more or less impervious to air-borne spores, 19 × 10 ft., was erected on one of my wheat plots at Dehra Dun on December 18th, 1904. Yellow rust was first observed in the field on January 1st, 1905. The tent was opened on February 11th, by which time a good deal of rust had developed on the surrounding wheat. The rusted leaves within the tent were counted, and 160 leaves bearing uredo sori collected within 1½ feet of the margin while the remainder of the area enclosed by the tent gave 24 only. So that in the marginal 78 square feet 160 leaves bore rust, while the central 112 square feet had only 24. Were the rusting of this wheat—a moderately susceptible one—due to a large number of latent germs in the grain, there is no explanation of this difference. As a matter of fact it was clear that the rusting of the margin was due to the entrance of aphides and other insects, carrying uredospores, at the ground level where the tent cloth was fastened down by stones only, and considerable numbers of these

[1] *Phil. Trans.* Vol. CXCVII. 1904.

[2] *Annals of Botany*, Vol. XIX. No. LXXIII. p. 125, 1905.

[3] *Ibid.* p. 39.

insects were found near the edge. They were fewer towards the centre, and secondary infection of the central part from the rust near the margin had not occurred to any great extent both from the shortness of time which had elapsed before the tent was opened and from the stillness of the air inside. We are therefore, I think, justified in concluding that susceptibility to rust depends on the liability of the leaves to uredospore attack, and that the latent germ, if it exist at all, can only do so in a comparatively small proportion of grains. No wheat is as yet known on which rust may not sometimes appear, so that immune sorts may bear the latent germ for all we know as often as the susceptible. And it also follows that experiments to test the existence of the germ by growing wheat in spore-tight cases, where only a few plants can be grown, are not likely to give positive results except accidentally, whether the hypothesis be true or not. Finally, if the presence or absence of the germ be independent of the susceptibility or immunity of the wheat to rust, then the behaviour of wheat in regard to Mendel's laws can have no bearing on the "mycoplasm" hypothesis.

NOTE ON THE INHERITANCE OF HORNS AND FACE COLOUR IN SHEEP.

By T. B. WOOD, M.A.,
Secretary Cambridge University Department of Agriculture.

THE following short note gives the preliminary results of an experiment which I have commenced on a small scale on my father's farm at Field Dalling, near Holt, in Norfolk.

The object of the experiment is to follow out the inheritance of various characters in sheep. In the autumn of 1903 my father placed at my disposal 30 of his Suffolk ewes. Suffolk sheep of both sexes are characterised by black faces and the absence of horns. I determined to cross them with a Dorset ram, Dorsets having in both sexes white faces and large horns. For the present, characters other than horns and face-colour are neglected.

From the 30 Suffolk ewes mated in the autumn of 1903 with a Dorset ram 43 lambs were born in the spring of 1904 Of these 25 were males and, unfortunately for the continuance of the experiment, only 16 females. All the latter were kept for breeding. Two rams were kept, the remaining 23 males being castrated and fattened during the winter of 1904–5.

In the autumn of 1904 the 16 cross-bred ewe lambs were mated with one of their half-brothers. Both the ram and the ewes were rather young to breed from, and the crop of lambs was small. Six of the ewes were barren, one aborted, one gave birth to two dead lambs, one produced a lamb which died immediately after birth. The remaining seven produced eight lambs, which were all reared.

The parents and both generations of offspring are illustrated in the accompanying plate. They are described below, so far as they vary in horns and in colour of face and legs. The numbers refer to those on the plate.

Parents.

1. Dorset Ram. Horns, white face and legs.
2. Suffolk Ewe. No horns, black face and legs.
3. Dorset Ewe. Horns, white face and legs.

First generation. Dorset Ram × Suffolk Ewes.

5. **Ram.** Horns, speckled face and legs. The second ram was

1. Dorset Ram.

2. Suffolk Ewe.

3. Dorset Ewe.

Parental Types.

4. Ewe.

5. Ram.

6. Ewe.

First Generation.

7. Ram.

8. Ewe.

9. Ram.

Second Generation.

10. Ram.

11. Ram.

12. Ewe.

Second Generation.

drowned when 3 months old. At this age both the rams had large horns of about the same size, and far larger than those that had been castrated.

4 & 6. Ewes. No horns, speckled face and legs.

Second generation. First cross ram first cross ewes.

10. Ram. Horns, white face and legs. There were two lambs of this type.
9. Ram. No horns, white face and legs.
7. Ram. Small horns, face white, with black rings round eyes; legs white, slightly speckled with black. There were two lambs, twins, of this type.
11. Ram. Small horns, speckled face and legs.
8. Ewe. No horns, speckled face and legs.
12. Ewe. Horns, face black, but with what appears to be rather wool than white hair on cheeks and forehead.

The Dorset ram used in 1904 was bought as pure bred from a Dorset breeder. The Suffolk ewes were not registered animals, but I have known the strain for some years, and have never seen either a horn produced or any white hair on face or legs. They may therefore be taken as pure in these characters.

It will be seen from the plate that the first generation hybrids have speckled faces and legs, and that in the second generation white faces, black faces, and speckled faces are produced: also that the first generation hybrid ewes have no horns, whilst the rams grow large horns. If, however, the rams are castrated the growth of their horns ceases. This accounts for the smallness of the horns in numbers 7 and 11 in the plate. In the second generation both horned and hornless animals of both sexes were produced.

A number of Dorset ewes were mated with a Suffolk ram at the University Farm in the autumn of 1904 in order to breed a number of cross-bred sheep reciprocal to the crosses bred at Dalling. The face-colour is again the same and the males are horned, the females hornless.

It would appear, therefore, that when black and white faced sheep are crossed the hybrids have speckled faces, and that these hybrids do not breed true *inter se,* but split into white faces, black faces, and speckled faces.

As regards horns, it appears that when Dorset sheep having horns in both sexes are crossed with hornless Suffolk sheep, the male offspring have horns, the females do not; or in other words, horns are dominant in males, recessive in females.

NOTE ON
"BERICHT ÜBER DIE ARBEITEN DER INTERNATIONALEN KOMMISSION FÜR DIE ANALYSE DER KUNSTDÜNGER UND FUTTERMITTEL DES V. INTERNATIONALEN KONGRESSES FÜR ANGEWANDTE CHEMIE ZU BERLIN, 1903."

By T. B. WOOD, M.A.

At the beginning of October, 1904, many agricultural chemists in England received copies of the above publication from the Secretary of the commission, Dr M. Ullmann, of Hamburg, together with a letter asking all who were willing to agree with the recommendations printed in the report to signify their assent to him. Copies of the report were circulated to members of the Chemical Committee of the Agricultural Education Association, and the recommendations were informally discussed at a meeting of the committee on Dec. 8th. It was suggested that a note should be published in order to call the attention of agricultural chemists to the subject, and facilitate further discussion.

The history of the matter is briefly as follows:—At the first International Congress of Applied Chemistry held at Brussels in 1894 the subject was brought forward, and was again discussed at the Paris Congress in 1896. At the Vienna Congress in 1898 a committee was appointed to investigate the methods of analysis used for manures and feeding stuffs in various countries, and to draw up a series of recommendations with a view to securing international uniformity of method. This committee presented an incomplete report at the Paris Congress in 1900, and its powers were prolonged in order that the final report might be presented at the Berlin Congress in 1903.

This was done, and the report and recommendations were presented and unanimously accepted.

The English translation of the recommendations is printed below:—

METHODS FOR THE ANALYSIS OF ARTIFICIAL MANURES AND FEEDING STUFFS ADOPTED AT THE GENERAL MEETING AT BERLIN ON JUNE 3, 1903, OF THE FIFTH INTERNATIONAL CONGRESS OF APPLIED CHEMISTRY.

The following publications are cited as references:

Die landwirtschaftlichen Versuchsstationen, Berlin, Paul Parey,
for artificial manures Bd. 38, 41, 43, 51, 52,
for feeding stuffs ... Bd. 36, 37, 38, 45, 49, 51.

Methoden zur Untersuchung der Kunstdüngemittel, 3. Aufl., Berlin, 1903, Weidemannsche Buchhandlung, herausgegeben vom Verein Deutscher Dünger-Fabrikanten.

U. S. Dept. of Agric. Div. of Chem., Washington, Bull. 46, 65, 81.

König, *die Untersuchung landw. und gewerbl. wichtiger Stoffe*, Berlin, 1898, Paul Parey.

Wiley, *Principles and Practice of Agricultural Analysis*, Vol. II. and III.

Sidersky, D., *Analyse des engrais*, Paris, 1901, Béranger.

Petermann, A., *Méthodes suivis dans l'analyse des matières fertilisantes*, Gembloux, 1901.

International Regulations for sampling wholesale Quantities of Raw Materials and Products of the Fertiliser Industry.

1. Samples not drawn in accordance with these regulations are to be refused by the official analysts, such refusal being recorded on the certificate.

2. Samples are only to be considered as properly taken, if drawn during unloading on railway or quay, in the presence of representatives of both parties, or by a sworn sampler, and in accordance with these regulations.

3. In the case of manufactured products, a sample is to be taken by means of a sampling iron from every tenth bag, or if the material is in bulk, from at least ten different places throughout the parcel.

4. In the case of shiploads of raw materials every 50th bag or bucketful during discharge (corresponding to 2 % of the whole) is to be set aside, and from this, after first crushing to at least the size of a hazel-nut, a sample is to be taken for the determination of moisture;

a further sample for the determination of the constituents of value is to be taken in the same way as in the case of manufactured products, after the sample has been reduced to a fine state by grinding and sifting.

5. The samples—in weight about 300 grams—are to be filled loosely into strong, clean and absolutely dry glass bottles.

6. At least three samples are to be taken. The bottles are to be hermetically closed and sealed by the persons conducting the sampling.

7. The labels are to be signed by the persons taking the sample and are to be attached by means of the wax used in sealing the bottles.

8. The samples are to be kept in a cool, dark, and dry place.

9. Materials of heterogeneous composition must be sufficiently reduced in size and mixed before bottling.

Preparation of Samples.

(*a*) Dry samples of phosphates or other artificial manures may be simply sifted and then mixed.

(*b*) In the case of damp materials, where the above procedure is not possible, the preparation must be confined to a careful mixing by hand.

(*c*) In the case of raw phosphates and animal charcoal, a water determination is to be made, as confirmatory evidence.

(*d*) In dealing with substances which are apt to lose water during grinding, the moisture is to be determined both before and after the preparation of the sample, the results of the analysis being afterwards calculated back into the original hygroscopic condition of the sample as received.

METHODS OF ANALYSIS.

A. Artificial Fertilisers.

1. Determination of Moisture.

Ten grams of the substance are used; the drying is conducted at 100° C. to constant weight; substances containing gypsum are dried three hours.

For potash salts the regulations of the Kalisyndicat at Leopoldshall-Stassfurt hold good.

II. Determination of Insoluble Matter.

Ten grams of the substance are used.

A. When the substance is dissolved in mineral acids, the silica is rendered insoluble and the total residue ignited.

B. When the substance is dissolved in water, the residue is dried at 100° C. to constant weight.

III. Determination of Phosphoric Acid.

A. *Method of making the Solutions.*

1. In the case of water-soluble P_2O_5 twenty grams of the substance are to be agitated for 30 minutes with about 800 c.cm. water in a litre bottle and then filled up to 1000 c.cm. The solution of so-called double superphosphates must be boiled with HNO_3 previous to precipitation of the P_2O_5 whereby any pyrophosphoric acid, which may be present, is converted into orthophosphoric acid.

For every 25 c.cm. of solution of double superphosphate 10 c.cm. concentrated HNO_3 must be taken.

N.B. When the amount of citrate-soluble phosphoric acid in superphosphates is required, the determination must be made according to Petermann's method.

2. For total phosphoric acid 5 grams of the substance are boiled with aqua regia or 20 c.cm. HNO_3 and 50 gms. concentrated H_2SO_4 for 30 minutes and made up to 500 c.cm.

3. P_2O_5 in Basic slag[1].

(*a*) Citric-soluble P_2O_5.

Five grams of the substance are placed in a 500 c.cm. flask with 5 c.cm. of alcohol to prevent caking and shaken with 2 % citric acid solution for one half-hour at 17°5 C. in a rotary apparatus which makes 30—40 revolutions per minute.

(*b*) Total P_2O_5.

Ten grams of the substance are placed in a 500 c.cm. flask, thoroughly mixed with a few c.cm. of water and boiled for 30 minutes with 50 c.cm. concentrated H_2SO_4, the flask being frequently shaken.

[1] Basic slag, which appears to contain coarse particles, is passed through a 2 mm. sieve; the portion, which remains behind, is slightly crushed. The determination of P_2O_5 is made in the portion which passes through the sieve, the result being calculated so as to include the portion which remains behind.

B. *Analysis of the Solutions.*

1. Molybdate-method according to Fresenius and P. Wagner.
2. Citrate method.
3. Free acid.

   (*a*) Total of free acid: The aqueous solution A 1 is titrated with a solution of NaOH, using methyl orange as an indicator, or

   (*b*) Free phosphoric acid: An alcoholic solution is used for making a gravimetric determination.

IV. Determination of Ferric Oxide and Alumina.

This determination must be made either according to the method of Eugen Glaser[1] as improved by R. Jones[2], or, in the case of the determination of alumina, according to Henri Lasne[3]. The method adopted must be mentioned.

V. Determination of Nitrogen.

1. *Nitric Nitrogen.*

Only direct methods must be used.

(*a*) Reduction methods according to Bottcher[4], Ulsch, Devarda and Kjeldahl-Jodlbauer.

(*b*) Gasometric methods. Lunge, Schloesing-Grandeau.

2. *Nitrogen present as Ammonia.*

The determination must be made by distillation with magnesia. With ammonia-superphosphates the solution given under III. A. 1 must be used.

3. *Total Nitrogen.*

In presence of nitrates this determination must be made according to Kjeldahl-Jodlbauer.

4. *Organic Nitrogen.*

In the absence of nitrates and ammonia the determination must be made according to Kjeldahl or by combustion with soda lime.

[1] Glaser, *Zeitschr. f. angew. Chemie*, 1889, S. 636, *s. a. Landw. Vers.-Stat.*, Bd. 38, S. 284.

[2] R. Jones, *Zeitschr. f. angew. Chemie*, 1891, S. 3, *s. a. Fresenius Zeitschr.*, 30, S. 748.

[3] Lasne, *Bull. Soc. Chim.*, T. 15, S. 146 u. 237, *s. a. Chem. Ztg.*, Repert. 1896, S. 47 u. 65.

[4] Early method of Kühn, *Landw. Vers.-Stat.*, Bd. 41, S. 165 u. 379.

VI. Determination of Potash.

This determination must always be made with platinum chloride or with perchloric acid. The method adopted must be specified.

VII. Determination of Lime and Magnesia.

In lime used as a fertiliser and in chalky clay this determination can be made either according to the titration method of Tacke or by the usual gravimetric method. The method adopted must be mentioned.

B. Feeding Stuffs.

Preparation of samples.

Samples of all feeding stuffs must be passed through a 1 mm. sieve, if possible.

I. Determination of Moisture.

Five grams of the substance are dried for three hours at 100° C. As regards linseed cake see III. 1.

II. Determination of Protein[1].

1. *Determination of Crude Proteïn.*

1—5 grams of the substance are taken. The nitrogen determination is made according to Kjeldahl or Gunning-Atterberg and the amount of nitrogen found is multiplied by 6·25. In the case of feeding stuffs which are difficult to dissolve, such as cotton-seed meal, peanut meal, etc. an addition of phosphoric anhydride is recommended.

2. *Determination of Albuminoid Nitrogen.*

The determination is made according to Stutzer or Kellner. The method employed must be specified.

3. *Determination of the Digestible Proteïn.*

Stutzer's method improved by G. Kühn is to be used. Instead of gastric juice commercial pepsin can be employed, with restrictions according to Wedemeyer.

[1] In feeding stuffs, where the carbohydrates have an accepted nutritive value, the determination of the value of the nutritive constituents from a commercial standpoint is made on the basis of the ratio 3 : 3 : 1 for Proteïn : Fat : Carbohydrates. (*VII Hauptversammlung des Verbandes landwirtschaftlicher Versuchsstationen im Deutschen Reiche*, Kiel, 1895.)

III. Determination of the Fat.

1. Feeding stuffs must be dried for three hours at 95° and in no case above 100°. In the case of linseed cake and other cake containing drying oils this can be done in an atmosphere of hydrogen or coal gas or only one hour at 100°. The ether used for the extraction must contain neither alcohol nor water. The extraction must be a complete one. The dried extract need not be soluble in ether.

2. Molasses feeds. 25 grams of substance are to be dried for three hours at 80° C. and ground when cool. Five grams of the powder must be washed out in a Gooch crucible with about 100 c.cm. cold water, added drop by drop. The residue to be dried at 95° and extracted by ether.

IV. Determination of Nitrogen-free Extract.

(*a*) This is usually obtained by difference after all the other constituents have been determined.

(*b*) For the determination of sugar the regulations of the International Sugar Commission hold good.

V. Determination of Crude Fibre.

According to Weende's method, three grams of substance, from which the fat (if present) has been extracted, are boiled with 200 c.cm. H_2SO_4 of 1·25 % and 200 c.cm. of potassium hydrate solution of 1·25 %. Each boiling must last ½ hour, water being added to replace the evaporated portion. Each treatment with acid or alkali must be followed by a boiling with water. The residue to be washed with hot alcohol, then with ether, and dried to a constant weight. The ash of the residue must be subtracted.

VI. Determinations of the Ash.

Five grams of the substance are incinerated and the residue is carefully weighed.

VII. Determination of the Sand or Mineral Ingredients.

The examination of all feeding stuffs for sand or mineral admixtures is obligatory. When the preliminary examination shows the presence of more than normal amounts a quantitative determination must be made. The result to be communicated to the remitter of the sample when the preliminary examination is ratified, at all events in all cases where the contents show more than 1 %.

The acceptance of these methods for the analysis of artificial manures and feeding stuffs at the general meeting of sections I and VII on Thursday, June 4, 1903, and at the general meeting of the Congress on

Monday, June 8, 1903, constitutes a second reading, the first reading having taken place at Paris in 1900.

As will be seen the labours of the International Commission deputed by the Berlin Congress to deal with the subject of the analysis of artificial manures and feeding stuffs have resulted in a definite agreement being arrived at.

Leaving out the sections on the sampling of wholesale quantities of raw materials, and preparation of samples, the rest of the recommendations may be divided into two, those that aim at establishing uniform conventional methods (for instance A. III. 1, defining water-soluble P_2O_5, and B. V. defining crude fibre), and those that attempt to dictate which particular one of many absolute methods shall be used (for instance A. V. 1, 2, 3, 4). With regard to the former it is no doubt desirable for many reasons that there should be a wide agreement on purely conventional methods, but the need of uniformity in the latter class is by no means apparent. It would certainly be for the general good if all analysts would agree for instance to determine fibre in the same way, for the result must vary with details of method, but no useful purpose would be served by all analysts using exactly the same method of estimating nitrogen, for the percentage of nitrogen in a substance is a fact which admits of accurate determination in more than one way.

At a meeting of the Agricultural Education Association it was decided to give the recommendations which define conventions (indicated by larger print in the accompanying text) careful consideration, as it is eminently desirable that English chemists should as far as possible fall into line.

VARIATION IN THE CHEMICAL COMPOSITION OF THE SWEDE.

On page 258 Mr A. D. Hall has made some criticisms on the figures contained in my paper, named above.

The first part of his remarks, dealing with the comparative magnitude of errors and factors, would apply to any investigation. Providing any such investigation were fairly extensive, there should be cases where a "factor" would approach zero (see page 105), compared with which any small error must approach infinity.

As I pointed out on page 100, the extreme seasonal variation is 4·64 per cent., and on page 98 the extreme variation due to the farm is 1·95 per cent., and to the variety 1·85 per cent., compared with which the difference between duplicates (·38 per cent.) is small. By averaging many results the error becomes smaller.

Mr Hall then writes, "Mr Collins's argument would be more convincing if he could give us some idea of the degree of accuracy to be expected in his various 'factors.'" This has already been done in Table X (page 103 *et seq.*) and in Table VII (page 99). There is no Waterloo swede in my paper; but assuming that this is a misprint for Kangaroo, the following comparison of variety factors results:—

(*a*) Holborn Elephant. Mr Hall's calculation, Maximum + ·265, Minimum + ·055; my calculation (page 103), + ·26 and + ·08 respectively. There is no essential difference between Mr Hall's calculation and mine, except that in using two places of decimals I could plead convention, whereas Mr Hall's use of three places of decimals is hard to justify.

(*b*) Holborn Kangaroo. Mr Hall's figures, + ·32 and + ·08: my figures (page 103), + ·31 and + ·09. Again no essential difference.

Mr Hall then refers to "Eshott in 1903" and immediately after to "Eshott in 1902." I imagine that here is a second misprint, but

as I cannot guess which year is correct, I must leave the matter alone.

Mr Hall then asks me to review my results "from the point of view of the relative magnitude of the 'factors' and of the probable errors involved in their determination." Mr Hall's own calculations show that this error is about ± ·1 per cent., and in my paper (page 103 *et seq.*) I have shown the errors to be of about the same magnitude (± ·03 to ± ·12). In my conclusion I state, "These analyses and calculations now enable us to draw up a list of varieties in order of merit (see Table VIII)." Anyone looking at Table VIII will see that I have struck out the second decimal place, which is much the same thing as stating that the errors are about ± ·1. Hence Mr Hall's final request has already been carried out for all essential purposes.

S. H. COLLINS.

THE AMOUNT AND COMPOSITION OF THE DRAINAGE THROUGH UNMANURED AND UNCROPPED LAND, BARNFIELD, ROTHAMSTED.

BY N. H. J. MILLER, PH.D., F.I.C.

(*Lawes Agricultural Trust.*)

DURING the last sixty years numerous percolation and evaporation experiments have been made in this country and elsewhere. The method employed has been that originally used by Dalton, which has the advantage that the chemical and physical properties of the soil may, if desired, be thoroughly investigated. In addition to these experiments in which the evaporation from the soil, or from the soil with vegetation, is estimated by deducting the amount of drainage from the rainfall of the same period, numerous determinations of soil moisture have been made in the United States, from which evaporation may be directly determined. The difference between the estimated evaporation and the rainfall gives of course the amount of percolation.

Recently, King (9) has determined the evaporation from soils supplied from below with a constant water-supply, by means of large cylinders 4 feet in diameter and 2 feet deep. He has also determined the amounts of water evaporated by plants growing in similar cylinders 4 feet deep.

The Rothamsted gauges differ from those of Dalton in containing undisturbed soil. Soil which has been put into cylinders and subjected to the action of rain, will no doubt, as time goes on, acquire a more and more natural condition of consolidation, but we cannot know when this desirable condition is completed and can only take it for granted after a considerable time. The Barnfield gauges are free from this disadvantage, and as a means of measuring drainage, which is what they were mainly intended for, leave very little to be desired. As regards, however, the

relation of the constituents of the drainage to those of the soil, our knowledge must always be somewhat imperfect, since it is obviously impossible to obtain exact estimates of what the soil originally contained.

The results relating to the amounts of drainage and of nitrogen as nitrates in the drainage have been published each year from 1882 to 1901 in the Rothamsted "*Memoranda*" and recently in "*Field Plans.*" Collected results relating to percolation only were published by Gilbert in 1891 (5), and more recently by R. H. Scott (7); whilst the more complete paper of Lawes, Gilbert, and Warington (3) deals with the whole subject, and contains the chemical results up to April, 1881.

On the present occasion it is proposed to bring together the whole of the results from the commencement. It will, however, be desirable first of all to give a short account of the gauges, as the earlier papers on the subject are not always accessible.

The three Rothamsted drain-gauges, having each an area of 1/1000th of an acre, were constructed in the summer of 1870 by undermining the soil at the desired depths (20, 40, and 60 inches respectively), and inserting perforated iron plates beneath the soil to support it as the undermining proceeded. When this was completed, trenches were made on the other three sides of the blocks of soil, and these were then isolated by means of 4½ inch brick walls. The external soil was then returned.

In 1874, leakage from the outside being suspected, the outsides of the walls of the gauges were exposed and covered with cement, and their thickness increased by another 4½ inches of bricks. In 1879, one of the walls of the 20-inch gauge received an extra coating of cement on its outer surface. Since then no structural alteration has been made in any of the gauges.

The drainage passing through the perforated iron plates which support the soil, falls into zinc funnels and flows from these into the measuring cylinders. During the first three years, however, the drainage was collected in carboys and weighed.

The Rothamsted soil[1] may be described as a rather heavy loam, with a reddish-yellow subsoil over chalk. Both the surface and the subsoil contain very large, and also very variable, amounts of flints.

As regards the cropping and manuring of the portion of the field on which the gauges were built it should be stated that before 1870 it

[1] H. B. Woodward, 'Report on the Soils and Subsoils of the Rothamsted Estate,' *Summary of Progress of the Geological Survey for* 1908.

had been under ordinary arable cultivation, artificial manures generally with guano, being employed. In 1870 the land was fallow.

In June, 1870, samples of soil were taken near the position now occupied by the gauges, both on the bare ground and on the barley land beyond. In the following table are given the results of nitrogen determinations made at the time in the samples from the bare ground, together with more recent determinations of calcium carbonate and chlorine. The amounts per acre are calculated from average weights of Rothamsted soils generally: for the first 9 inches, 2,400,000 lbs., for the second 9 inches 2,650,000, for the third and fourth 9 inches 2,700,000, and for the lower depths 2,800,000 lbs. per acre.

TABLE I.

Amounts of Nitrogen, Chlorine, and Calcium Carbonate in Soil Samples taken from the Bare Ground near the Gauges in 1870.

	In fine, dry soil			Per Acre		
	Nitrogen	Chlorine	Calcium carbonate	Nitrogen	Chlorine	Calcium carbonate
	per cent.	per cent.	per cent.	lbs.	lbs.	lbs.
First 9 inches	0·146	0·00242	3·06	3,504	58 1	73,440
Second ,, ...	0·078	0·00195	0 32	2,067	51·7	8,480
Third ,, ..	0·076	0·00190	0·12	2,052	51·3	3,240
Fourth ,, ..	0·076	0·00192	0·15	2,052	51·8	4,050
Fifth ,, ...	0·061	0·00199	0·11	1,708	55·7	3,080
Sixth ,, ...	0·057	0·00158	0·18	1,596	44·2	5,040

According to these estimates the initial amounts of the three constituents in the soil of the 20-, 40-, and 60-inch gauges will be in lbs. per acre as follows:

	Nitrogen	Chlorine	Calcium carbonate
Soil 20 inches deep.... ..	6,027	121	82,610
,, 40 ,, ...	10,434	238	90,579
,, 60 ,, ...	14,043	342	100,690

I. PERCOLATION AND EVAPORATION.

The average yearly amounts of water percolating through 20, 40, and 60 inches of soil are very similar and amount to about 14 inches, or approximately half the rainfall. The results obtained with the

20- and 60-inch gauges are indeed practically identical[1]; whilst the 40-inch gauge yields on the average nearly 1 inch more drainage than the others.

TABLE II.

Yearly Amounts of Drainage through 20, 40, *and* 60 *inches of Bare Soil.*

Sept. 1 to Aug. 31	Rain-fall	Drainage			Drainage °/₀ of Rainfall			Evaporation		
		20-inch gauge	40-inch gauge	60-inch gauge	20-inch gauge	40-inch gauge	60-inch gauge	20-inch gauge	40-inch gauge	60-inch gauge
	inches	inches	inches	inches				inches	inches	inches
1870–1	27·55	9·64	9·42	5·81	35·0	34·2	21·1	17·91	18·13	21·74
1–2	29·02	9·69	9·39	8·24	33·4	32·4	28·4	19·33	19·63	20·78
2–3	30·66	14·35	13·67	12·03	46·8	44 6	39 2	16·31	16·99	18·63
3–4	21·69	5·74	5·40	3 94	26·5	24·9	18 2	15·95	16·29	17·75
4–5	31·61	12·25	12·72	10·30	38·7	40·2	32·6	19·36	18·89	21·31
5–6	31·98	14·75	16·87	15·46	46·1	52·7	48·3	17·23	15·11	16·52
6–7	39·28	19·63	22·07	20·20	50·0	56·2	51·4	19·65	17·21	19·08
7–8	32·65	14·72	16·44	14·84	45·1	50·4	45·5	17·93	16·21	17·81
8–9	41·05	24·44	26·03	24 38	59·5	63·4	59·4	16·61	15 02	16·67
9–80	21·36	6·89	7·39	6·50	32·3	34·6	30·4	14·47	13·97	14·86
1880–1	36·77	22·38	22·84	21·26	60·9	62·1	57·8	14·39	13·93	15·51
1–2	32·31	15·81	16·08	14·32	48·9	49·8	44·3	16·50	16·23	17·99
2–3	34·71	20·82	21·72	19·72	60·0	62·6	56·8	13·89	12·99	14·99
3–4	25·77	11·86	12·00	11·21	46·0	46 6	43·5	13·91	13·77	14·56
4–5	26·78	14·82	15·14	13·98	55·3	56 5	52·2	11·96	11·64	12·80
5–6	31·02	17·37	18·41	16·57	56·0	59·3	53 4	13·65	12·61	14·45
6–7	23·61	10·64	12·58	11·72	45·1	53·3	49·6	12·97	11·03	11·89
7–8	30·50	13·96	15·58	14·67	45·7	51·1	48·1	16·54	14·92	15·88
8–9	30·09	14·64	15·82	14·33	48·7	52 6	47·6	15·45	14·27	15·76
9–90	27·43	13·16	13·60	12·74	48·0	49·6	46·4	14·27	13·83	14·69
1890–1	23·41	9·95	9·70	9·73	42·5	41·4	41·6	13·46	13·71	13·68
1–2	29·68	16·50	17·43	16·47	55·6	58·7	55·5	13·18	12·25	13·21
2–3	24·08	11·58	12·35	12·10	48·1	51·3	50·3	12·50	11·73	11·98
3–4	29·55	13·36	14·11	14·07	45·2	47·7	47·6	16·19	15·44	15·48
4–5	28·94	15·50	16·95	16·31	53 5	58·6	56·4	13·44	11·99	12·63
5–6	24·37	9·84	10 75	10·35	40·4	44·1	42·5	14·53	13·62	14·02
6–7	37 24	21·88	23·86	22·80	58·8	64·1	61·2	15·36	13·38	14·44
7–8	19·51	5·95	6·66	6·47	30·5	34·1	33·2	13·56	12·85	13·04
8–9	24·70	11·99	12·48	12·48	48·6	50·5	50·5	12·71	12·22	12·22
9–1900	31·02	16·33	16·93	17·02	52·6	54·6	54·9	14·69	14·09	14·00
1900–1	24·30	10·91	12·35	11·92	44·9	50·8	49·1	13·39	11·95	12·38
1–2	23·26	8·75	9·82	9·44	37·6	40·1	40·6	14·51	13·94	13·82
2–3	31·25	16·33	17·09	17·59	52·3	54·7	56·3	14·92	14·16	13·66
3–4	31·50	17·68	17·92	18·29	56·1	56·9	58·1	13·82	13·58	13·21
4–5	25·30	10·10	10·45	10·36	39·9	41·3	40·9	15·20	14·85	14·94

[1] It may be mentioned that the summer of 1870, at the end of which the gauges were made, was very dry and that the soil must have lost considerable amounts of water by evaporation from the exposed sides, the deeper the gauge the greater, of course, the loss. Evidence of this is furnished by the first year's percolation results, the 20-inch gauge giving 9·64 and the 60-inch gauge only 5·81 inches. When this first year is excluded, the averages (34 years) for the two gauges differ by only 0·08 inch.

The yearly amounts of drainage show in each case (Table II) great variations, depending partly on the total rainfall and partly on the distribution of the rain during the year. Averages of several years arranged according to the magnitude of the rainfall show a regular increase in the amount of drainage (see Table III), but in individual years there may be low drainage with relatively high rainfall, and *vice versâ*. In the year 1881–2, for instance, a year of high rainfall, following a year of still greater rainfall, the percentage of drainage through 60 inches of soil was slightly below the average, although as a rule a high rainfall is coincident with a relatively higher amount of drainage. In 1889–90, a year of average rainfall, also following one of high rainfall, the amount of drainage was low in all three gauges. The generally small differences between the yearly drainage through 20 and 60 inches of soil seem to have no connexion with the amount of the rainfall, and are difficult to account for. During the first twenty-two years of the experiments the 20-inch gauge generally gave more drainage than the 60-inch gauge; during the last thirteen years the reverse has occurred without exception.

TABLE III.

Average Amounts of Drainage and Evaporation in years of Low, Average, and High Rainfall (60-inch Gauge), 1870–1 to 1904–5.

	Rainfall	Drainage		Evaporation
	inches	inches	per cent.	inches
Rainfall below 26 inches.....	23·45	9·69	41·3	13·76
,, 26—30 inches	28·42	12·52	44·1	15·90
,, above 30 inches......	33·35	17·11	51·3	16·24

The differences between the amounts of rain and drainage—due partly to evaporation and partly to retention by the soil, when we are dealing with individual years or months, and to evaporation alone in the case of averages of several years—show less variation from year to year than either rainfall or drainage. The evaporation from the 20-inch gauge has varied from 11·96 to 19·33 (average 15·13 inches), and from the 60-inch gauge from 11·89 to 21·74 (average 15·32 inches). Most of the high results were obtained in the first few years, during a period of unusually heavy rainfall.

Results of percolation experiments made by Dickinson and Evans (2) at Hemel Hempstead, with Dalton gauges containing soil covered with

grass, showed a yearly evaporation of 19·97 inches with a rainfall of 25·55 inches. Similar results were obtained by Greaves (1) at Lea Bridge, turfed soil evaporating 18·14 inches (average of 14 years). Greaves also determined the evaporation from a surface of water, which he found amounted to 20·66 inches per annum. The more recent water-evaporation experiments in St Pancras, London, published by Mill (8) gave, however, much lower results, the average yearly amount (19 harvest years) being only 15·55 inches.

TABLE IV.

Monthly Amounts of Drainage through 20, 40, *and* 60 *inches of Soil. Average* 35 *years.*

1870–1 to 1904–5	Rainfall	Drainage			Drainage per cent. of rain			Evaporation		
		20-inch gauge	40-inch gauge	60-inch gauge	20-inch gauge	40-inch gauge	60-inch gauge	20-inch gauge	40-inch gauge	60-inch gauge
	inches	inches	inches	inches				inches	inches	inches
September .	2·51	0 86	0·81	0·74	34·3	32·3	29·5	1·65	1·70	1·77
October....	3·23	1·83	1·80	1·64	56·7	55·7	50·8	1·40	1·43	1·59
November...	2·82	2·10	2·15	2·01	74·5	76·2	71·3	0·72	0·67	0·81
December..	2·52	2·02	2·14	2·01	80·2	84·9	79·8	0 50	0·38	0·51
January ..	2·29	1·79	2·02	1·92	78·2	88·2	83·8	0·50	0·27	0·37
February ..	1 94	1·39	1·53	1·44	71·7	78·9.	74·2	0·55	0·41	0·50
March	1·88	0·92	1·06	1·00	48·9	56·4	53·2	0·96	0·82	0·88
April. . . .	1·90	0·50	0·57	0·53	26·3	30·0	27·9	1·40	1·33	1·37
May .	2·08	0·47	0·54	0·49	22 6	26·0	23·6	1·61	1·54	1·59
June	2·41	0 65	0·67	0·64	27·0	27·8	26·6	1·76	1·74	1·77
July	2·70	0·68	0·69	0·65	25·2	25·6	24·1	2·02	2·01	2·05
August	2·69	0·63	0·63	0·58	23·4	23·4	21·6	2·06	2·06	2·11
Sept.—Dec.	11·08	6·81	6·90	6 40	61·5	62·3	57·8	4·27	4·18	4·68
Jan.—April	8·01	4·60	5·18	4·89	57·4	64·7	61·1	3·41	2·83	3·12
May—Aug.	9·88	2·43	2·53	2·36	24·6	25·6	23·9	7·45	7·35	7·52
Oct.—Mar.	14·68	10·05	10·70	10·02	68·5	72·9	68·3	4·63	3·98	4·66
April—Sept.	14·29	3·79	3·91	3·63	26·5	27·4	25·4	10·50	10·38	10·66
Year ..	28·97	13·84	14·61	13·65	47·8	50·4	47·1	15·13	14·36	15·32

With regard to monthly percolation the average results set out in Table IV show that the maximum drainage occurs in November, that it gradually decreases until May, after which there is a regular rise to September, followed by a considerable rise in October. The monthly differences between the drainage of the 20-inch gauge and that of the 60-inch gauge are very regular and are best shown as percentages of

the rain (Fig. 1). From January to May the 60-inch gauge yields a decreasing excess of drainage over the 20-inch gauge, whilst from June to December (particularly from September to November) the excess of drainage is from the 20 inch gauge. The differences are very difficult to account for and may be due to variations in temperature and consequently in viscosity (to which, presumably, the 20-inch gauge would be the more liable to be influenced), to barometric pressure, or may be connected with the access, escape, and retention of air which will vary according to the depth of the soil.

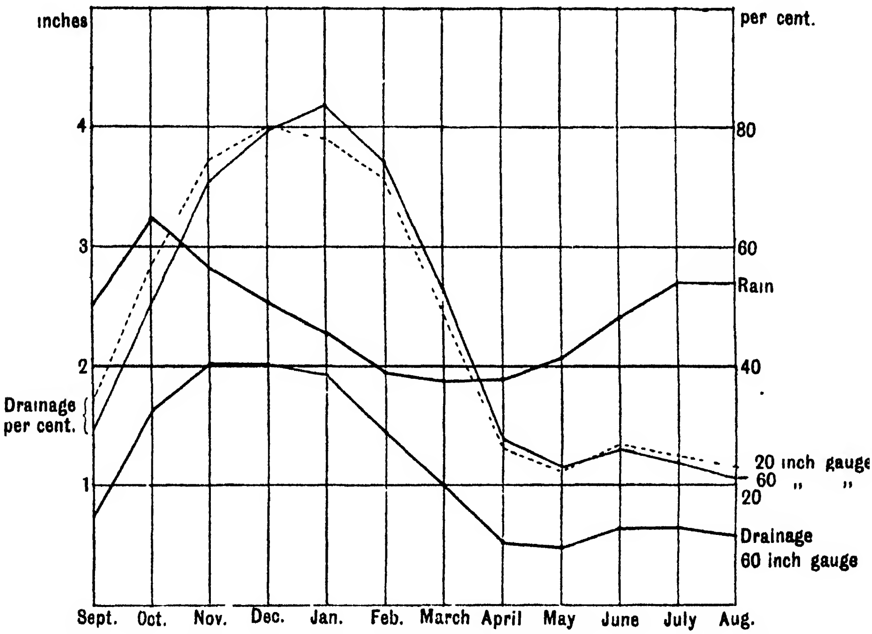

FIG. 1. Rainfall and drainage through 60 inches of soil. Drainage through 20 and 60 inches of soil per cent. of rain. Average 35 years.

In Wollny's (10) experiments with soil from 5 cm. to 30 cm. deep, it was found that the amount of drainage diminished with the depth of the soil up to a certain point (15 cm. of soil) and then increased. The results are, however, not comparable with those just described, as the deepest soil (30 cm.) was not much more than half the depth of the 20-inch gauge. The percentage of water in Wollny's soils increased considerably with the depth of the soil up to 20 cm., and then remained fairly constant.

The average number of days on which drainage has been recorded is 123 in the case of the 60-inch gauge. The monthly averages are as follows:

October	18·0 days	April	8·9 days
November	14·5 ,,	May	7·0
December	14·9	June	6·5
January	14·1	July	6·8
February	12·9	August	5·9
March	11·3	September	7·4

The number of rainy days (see this vol., p. 299) falls from 18 in October to 13 in March, and varies between 12 and 14 in the summer months.

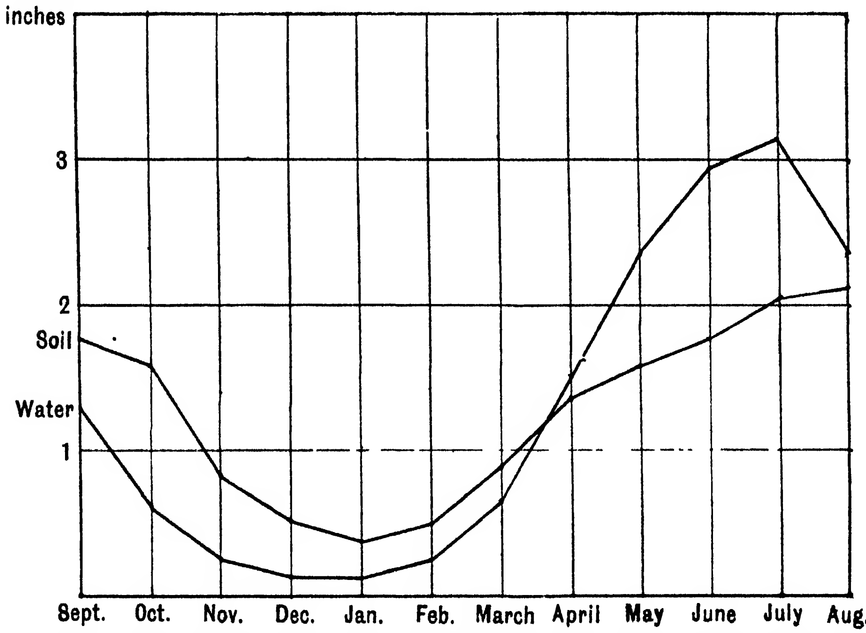

FIG. 2. Estimated evaporation from the soil of the 60-inch gauge; and evaporation from water (Mill).

A comparison of the monthly differences between rain and drainage with the amounts actually evaporated from a surface of water (Mill, *loc. cit.*), would seem to indicate that from March to September these differences are mainly due to evaporation, and that from October to February a good deal is due to retention by the soil. When, however, we select from the monthly results those which have followed a month at least of high rainfall, it is seen that in most cases the estimated

amounts of evaporation do not differ greatly from the average. With the exception of October it is probable that the average monthly results indicate almost exclusively evaporation. In October more of the difference between rainfall and drainage would seem to be due to absorption (Fig. 2).

An excess of drainage over the monthly rain has occurred on fifteen occasions, but always from November to March, and chiefly in January and February. On each occasion the excess has been observed in the case of the 40-inch gauge, whilst the 60- and 20-inch gauges have only yielded an excess on nine and seven occasions respectively. It is due either to the soil becoming frozen, or to an excess of water at the end of the month not having had time to percolate. Excesses of daily drainage over the amount of rain occur at all times of the year, and may be due to the rate of percolation being for a time slower than the supply of rain, or in some cases perhaps to a rise in temperature resulting in the diminished viscosity of the soil water.

It will now be desirable to consider the effects of drought and of high rainfall on the amounts of drainage and evaporation.

The total rainfall of January and February, 1893, was above the average, and the daily records indicate that the soil of the gauges was saturated at the end of each of these months. In fact there was on March 1 a large excess of drainage (0·259 inch through 20-inch gauge) over the rainfall (0·117 inch) owing to the excess of water not having had time to percolate. During the remainder of March (2—31) the rainfall was only 0·307 inch (making a total of 0·424 inch), and of this amount 0·124 inch, or 40 per cent., percolated. The evaporation for the whole month as indicated by the difference between rain and drainage would be only 9·7 per cent. of the rain; or, when the first day is excluded, 60 per cent. This is a decidedly high amount, due in part to the very large amount of sunshine—199 hours as against the average of 118 hours (see this vol., p. 299). During the next three months there were only 2·47 inches of rain and no drainage at all. In July, 3 inches of rain fell, but owing to the dried-up condition of the soil there was again practically no drainage (0·003 inch), and even the 0·64 inch which fell in the first three days of August failed to give drainage. The soil was, however, by this time again approaching a state of saturation and on August 5, with 0·25 inch of rain, 31 per cent. (= 0·077 inch) percolated through the 20-inch gauge. From August 6 to 11, 0·166 inch of rain fell but owing to evaporation there was again no drainage, and only 10 per cent. on the 12th with 0·09 inch of rain. After a week's interval of

fine days there were four rainy days on which altogether an inch of rain fell, with, however, only 0·03 inch of drainage. In the whole month of August there were 2·38 inches of rain of which only 4·9 per cent. percolated through the 20-inch gauge and much less through the other gauges; and it was not until the middle of October that regular drainage recommenced.

The results from March 2 may be summarized as follows:

1898	Rain inches	Drainage (20-inch gauge) inches	per cent.
March 2 to July 31............	5·78	0·127	2·2
,, ,, Aug. 31........	8·16	0·244	3·0
,, ,, Sept. 30............	9·30	0·244	2·6
October 1–31	4·46	2·749	61·6

The rainfall March—September was rather more than half the average amount.

Another period of drought, shorter than that just described, occurred in June and July, 1904. The rainfall of the previous months since February had been low, and in May, although 2·15 inches of rain fell, the drainage only amounted to 0·057 through 20, and 0·100 inch through 60 inches of soil. From June 1 to June 10 the rainfall was 0·155 inch and the drainage 0·035 and 0·059 inch respectively. On the 14th 0·284 inch fell, but there was no drainage. From that date to the end of the month the rain only amounted to 0·363 inch, whilst the 20- and 60-inch gauges gave 0·003 and 0·023 inch of drainage. The dry weather continued until July 25, the rain from the 1st to 24th only amounting to 0·35 inch, most of which fell on the first three days. On July 25, 1·44 inches of rain fell, and drainage was found in the cylinders of the gauges amounting to 0·217 inch in the case of the 20- and 0·185 inch in the 60-inch gauge, corresponding with 15 and 13 per cent. of the rainfall. In this case the difference between rain and drainage, 1·218 inches in the 20-inch gauge and 1·250 inches in the 60-inch gauge, would no doubt be due to a great extent to retention by the unusually dry soil. But loss by evaporation was no doubt considerable, the amount of sunshine during the month being much above the average.

With heavy rainfall in the summer we have, coincidently, high percentages of drainage, but the effect of the rapid evaporation from the soil soon shows itself. In June, 1903, after an average rainfall in May, there was a fall of 6·12 inches, of which 4·81 inches, or nearly 79 per cent. percolated through 20 inches of soil. In July, the rainfall was 4·09 inches, very considerably over the average, and the percolation

in the 20-inch gauge was 1·82 inch, or 44 per cent. In August there was again a great excess of rain (3·96 inches) and also an excess of drainage (1·35 inches), but the percentage of drainage fell to 34 per cent. All these figures are abnormally high, but they show the great reduction in the relation of drainage to rain in the summer months. In September, 1903, the rainfall was still somewhat in excess of the average (2·75 inches), whilst the drainage (0·87 inch) was quite normal for the month. The very high rainfall in October, amounting to 6·32 inches, resulted in 5·12 inches of drainage through 20 inches of soil, corresponding with 82 per cent., or about 4 per cent. more than in June with a similar rainfall.

Notwithstanding the wet condition of the soil during this period it will be seen that the amount of evaporation was, on the whole, about the same as under average conditions.

II. COMPOSITION OF THE DRAINAGE.

1. *Nitrogen as Nitrates.*

In a previous paper (this vol. p. 288) it was shown that the rain supplies annually to the soil about five pounds of nitrogen. Of this amount about four pounds represent nitrates and ammonia which would be rapidly nitrified in the soil, and the rest, about one pound, represents organic compounds which may be either more or less readily nitrified than the organic nitrogen of the soil. In any case the total amount is very small as compared with the amounts found in the drainage through the soil of the gauges.

During the last 28 years the average loss of nitrogen in the gauges has been 31·4 lbs. per acre per annum. The annual losses (see Table V) vary from year to year considerably, partly owing to differences in the rainfall and partly to the distribution of the rain. There is, in addition, as will be shown later on, a slight tendency for the nitrates to decrease, but this only manifests itself when successive averages of several years are compared. The yearly amounts of nitrogen in the drainage of the 60-inch gauge have varied from 61 to 15 lbs. with the highest recorded rainfall in 1878–9 (41·05 inches) and the lowest rainfall in 1897–8 (19·51 inches). Both years were preceded by years of high rainfall. In 1898–9 when the rainfall was, for a second year, unusually low, the 60-inch gauge lost nearly 31 lbs. of nitrogen; and in 1899–1900 nearly 38 lbs. The very low results of 1897–8 are partly due to the

complete washing-out to which the gauges were subjected the year before, when the 60-inch gauge lost 41·4 lbs. of nitrogen. It is probable, however, that the 19 years between the maximum and minimum losses have helped to increase the difference.

TABLE V.

Yearly Amounts of Nitrogen as Nitrates in the Drainage through 20, 40, and 60 inches of Soil.

Sept. 1 to Aug. 31	Rainfall	Drainage			Nitrogen, lbs. per acre		
		Soil 20 inches deep	Soil 40 inches deep	Soil 60 inches deep	Soil 20 inches deep	Soil 40 inches deep	Soil 60 inches deep
	inches	inches	inches	inches	lbs	lbs.	lbs.
1877–8	32·65	14·72	16·44	14·84	44·75	39·53	45·92
1878–9	41·05	24·44	26·03	24·38	59·36	46·52	60·94
1879–80	21·36	6·89	7·39	6·50	27·03	17 87	20·19
1880–1	36·77	22·38	22·84	21·26	57·78	44·22	49·95
1881–2	32·31	15·81	16·08	14·32	32·93	31·74	35·24
1882–3	34·71	20·82	21·72	19·72	32 67	36·08	38·26
1883–4	25·77	11·86	12·00	11·21	29·31	26·85	26·89
1884–5	26·78	14·82	15·14	13·98	39·55	36·71	33·86
1885–6	31·02	17·37	18·41	16·57	34·49	32·27	34·36
1886–7	23·61	10·64	12·58	11·72	25·28	21·88	24·98
1887–8	30·50	13·96	15·58	14·67	43·10	36·90	35·67
1888–9	30 09	14·64	15·82	14·33	31·96	29·25	30·50
1889–90	27·43	13·16	13·60	12·74	27·61	24·94	28·41
1890–1	23·41	9·95	9·70	9·73	25·70	19 90	22·04
1891–2	29·68	16·50	17·43	16·47	29 39	28 45	33·43
1892–3	24 08	11·58	12·35	12·10	22·61	20 40	23·72
1893–4	29·55	13·36	14 11	14·07	40·94	31 53	34·52
1894 5	28·94	15·50	16·95	16 31	37 12	33 18	34·36
1895–6	24·37	9·84	10 75	10·35	23·18	22·77	22·78
1896–7	37·24	21 88	23·86	22·80	36·62	35·77	41·40
1897–8	19·51	5·95	6·66	6·47	18·20	13·95	15·01
1898–9	24·70	11·99	12·48	12·48	33·23	28·65	30·91
1899–1900	31·02	16·33	16·93	17·02	37·00	33·85	37·68
1900–1	24·30	10 91	12 35	11·92	33·68	28·24	29·26
1901–2	23·26	8 75	9·32	9·44	29·12	21·65	22·11
1902–3	31·25	16·33	17·09	17·59	33·70	30·98	32·73
1903–4	31·52	17·68	17·92	18·29	16·38	20·87	24·36
1904–5	25·30	10·10	10·45	10·36	23·25	21·58	22·08

The amount of water percolating through the soils of the gauges reaches its maximum, as already shown, in November, the highest rainfall being in October. The drainage then decreases until April, which is the month of minimum drainage; increases very slightly in May and June (Table VI). After a slight fall in July, the drainage again increases until November.

TABLE VI.

Monthly Amounts of Nitrogen as Nitrates in the Drainage through 20, 40, and 60 inches of Soil.

1877–8 to 1904–5	Rainfall	Drainage			Nitrogen as Nitrates per million			Nitrogen as Nitrates per acre			Nitrogen to 1 Chlorine		
		20-inch gauge	40-inch gauge	60-inch gauge	20-inch gauge	40-inch gauge	60-inch gauge	20-inch gauge	40-inch gauge	60-inch gauge	20-inch gauge	40-inch gauge	60-inch gauge
	inches	inches	inches	inches				lbs.	lbs.	lbs.			
September......	2·35	0·84	0·83	0·77	16·05	11·40	12·23	3·05	2·14	2·13	3·55	2·52	2·84
October	3·20	1·88	1·88	1·75	13·26	10·34	11·42	5·64	4·40	4·52	2·97	2·27	2·54
November	2·84	2·16	2·22	2·12	12·18	10·19	11·05	5·95	5·12	5·30	2·55	2·10	2·38
December	2·51	2·04	2·17	2·09	9·90	8 76	9·90	4·57	4·30	4·68	2·06	1·85	2·17
January........	2·06	1·67	1·87	1·83	7·25	7·14	8·45	2·74	3·02	3·50	1·70	1·56	1·94
February	1·98	1·51	1·66	1·58	6·44	6·28	7·89	2·20	2·36	2·82	1·53	1·49	1·94
March	1·90	0·97	1·12	1·06	6·88	6·75	8·17	1·51	1·71	1·96	1·37	1·34	1·69
April	1·84	0·48	0·55	0·51	7·92	7·07	9·27	0·86	0·88	1·07	1·75	1·57	2·06
May	2·13	0·54	0·61	0·56	8·19	7·03	8·84	1·00	0·97	1·12	1·72	1·54	1·96
June	2·41	0·72	0·75	0·73	8·23	7·19	8·36	1·34	1·22	1·38	1·63	1·40	1·66
July	2·57	0·64	0·65	0·62	12·09	9·04	10·34	1·75	1·33	1·45	2·46	1·90	2·20
August	2·86	0·77	0·76	0·72	14·12	9·94	11·72	2·46	1·71	1·91	3·15	2·22	2·62
Oct.—March ..	14·49	10·23	10·92	10·43	9·77	8·46	9·65	22·61	20·91	22·78	2·13	1·82	2·15
April—Sept. . .	14·16	3·99	4·15	3·91	11·59	8·79	10·24	10·46	8·25	9·06	2·47	1·88	2·23
Year......	28·65	14·22	15·07	14·34	10·28	8·55	9·81	33·07	29·16	31·84	2·23	1·84	2·17

The monthly results set out in Table VI show that the highest amounts of nitrogen per million in the drainage through 20 and 60 inches of soil occur in September, whilst the lowest amounts are found in February. The extremes are 16·05 and 6·44 for the 20-inch gauge and 12·23 and 7·89 per million in the deepest gauge The amounts for the year are quite similar in the two gauges, so that the monthly differences are merely due to the mode of distribution. The soil water in the deeper gauge evidently becomes more mixed than that of the 20-inch gauge (Fig. 3).

As regards the amounts of nitrogen withdrawn from the soil in the different months, the lowest, unlike the minimum concentration, is in April. This is followed by a gradual and fairly regular rise until September, and then by a rapid rise until November, when the maximum loss occurs. This is succeeded by a fall until April.

The relation of nitric nitrogen to the quantity of the drainage is somewhat complicated. In the first place, the amount of nitrification will depend on the temperature and on the degree of moisture in the upper portions of the soil. Then to completely extract the whole of recently-produced nitrates would of course require an amount of rain more than sufficient to expel the whole of the water existing in the soil. Results of determinations of moisture made in Broadbalk soils (4) in 1869 after much rain, showed that when saturated the soil of the unmanured plot contained down to 3 feet 23 per cent. of water. This would be equivalent to about 7·6 inches of water in the soil of the 20-inch gauge, 15·2 inches in the 40-inch, and 22·8 inches in the 60-inch gauge. To completely extract the gauges would, therefore, require considerably more rain than is generally realised. The comparatively low amounts of nitric nitrogen in the drainage of the early summer months, taken in conjunction with the small amounts of drainage, indicate that most of the drainage in these months is derived from the subsoil. It is not until September that the waters richest in nitrates are obtained, whilst high results continue to be obtained throughout October and November, notwithstanding the diluted condition of the drainage at this time and the comparative inactivity of nitrifying organisms.

It will be noticed that whilst the total drainage of the 20-inch and 60-inch gauges are almost the same, that of the 40-inch gauge is distinctly higher. The total nitric nitrogen in the drainage of the 20- and 60-inch gauges also differs by rather more than 1 lb. per acre, whilst that of the 40-inch gauge is not higher, as might be expected from the higher

drainage, but about 3 lbs., or 10 per cent. lower than the mean of the other two gauges. The difference is still more marked when the

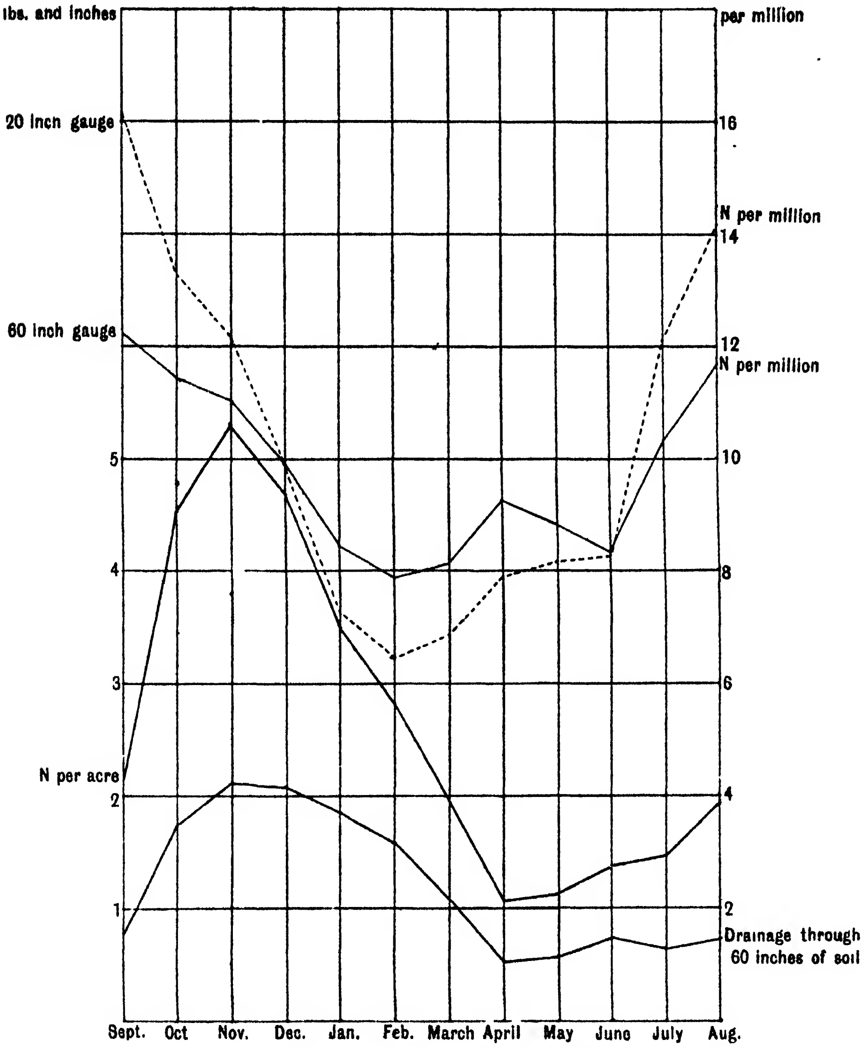

FIG. 3. Drainage through 60 inches of soil, and loss of nitrogen per acre. Nitrogen per million in the drainage through 20 and 60 inches of soil. Average 28 years.

nitrogen is considered in relation to chlorine in the three drainage waters (Table VI). The 20-inch and 60-inch gauges give almost identical results, the 40-inch gauge a much lower result (for the year).

A good example of the effect of drought on the composition of subsequent drainage is afforded by the dry period in 1893, already referred to in connection with the percolation and evaporation.

TABLE VII.

Effect of Dry Weather on the Amount and Composition of subsequent Drainage. (20-inch Gauge.)

1893	Rainfall	Drainage	Per million		Per acre		N to 1 Cl
			Nitrogen	Chlorine	Nitrogen	Chlorine	
	inches	inches			lbs.	lbs.	
April to June	2·47	—	—	—	—	—	—
July	3·00	0·003	16·8	7·4	0·01	0·005	2·0
August	2·38	0·12	10·5	4·2	0·28	0·11	2·5
September	1·14	—	—	—	—	—	—
October	4·46	2·75	22·0	5·9	13·68	3·67	3·7
November............	2·93	1·84	18·1	4·7	7·54	1·96	3·8
December..	2·63	2·27	13·3	5·7	6·84	2·93	2·3

The rainfall since August, 1892, had been fairly normal with the exception of March, when the rain and drainage amounted respectively to 0·42 and 0·38 inch. The nitrates and chlorine were rather below the average, the former decreasing irregularly from 14·9 in September to 5·4 in March, the latter from 5·5 to 3·0 per million. The renewed drainage of July was probably, in view of the very high chlorine results, surface water concentrated by evaporation. In August the amount of chlorine shows that the drainage was at any rate not more concentrated than usual at this time of the year, whilst the decrease in the, still high, amount of nitric acid would indicate more subsoil water, and hence normal drainage. The next results, in October (the highest of all but two recorded for this month), clearly indicate that the water which had been near the surface during the summer months was now passing through the soil. The nitrogen then decreased until by January the drainage contained about the average amount (7·3 per million).

The only higher amounts of nitrogen recorded occurred in two consecutive months, September and October, 1887, after a year of very low rainfall (23·61 inches).

With average losses of 29 to 33 lbs. of nitrogen per acre, or deducting 5 lbs. for nitrogen contributed by rain, of 24 to 28 lbs., it would be

natural to expect some indication of a gradual exhaustion of the unmanured soil after a period of nearly 30 years. The results recorded in Table V, which gives the annual loss in each year, show, however, such wide differences, depending on the amount of rain and drainage, that it cannot be said that we have absolutely certain indication of actual or approaching exhaustion. In some of the early years the amounts of nitrogen were very large, but so were also the amounts of drainage. The following summary, giving averages for four periods of seven years, shows very little indication of a continuous falling off, especially when the amount of drainage is taken into account.

TABLE VIII.

Average Losses of Nitrogen in the Drainage through 20, 40, *and* 60 *inches of Soil during Four Periods of Seven Years.*

Harvest years Sept. 1—Aug. 31	Rainfall	Drainage			Nitrogen as Nitrates per acre		
		Soil 20 inches deep	Soil 40 inches deep	Soil 60 inches deep	Soil 20 inches deep	Soil 40 inches deep	Soil 60 inches deep
	inches	inches	inches	inches	lbs.	lbs.	lbs.
1877–8 to 1883–4.	32·09	16·70	17·50	16·03	40·55	34·69	39·62
1884–5 to 1890–1	27·55	13·51	14·40	13·39	32·53	28·84	29 97
1891–2 to 1897–8	27·62	13·52	14·59	14·08	29·72	26·58	29·32
1898–9 to 1904–5	27·33	13·16	13·79	13·87	29 48	26·55	28·45

TABLE IX.

Relation of Nitrogen as Nitrates to Chlorine in the Drainage during Four Periods of Seven Years.

Harvest years Sept. 1—Aug. 31	Nitrogen to Chlorine = 1		
	20-inch gauge	40-inch gauge	60-inch gauge
1877–8 to 1883–4.....	2·76	2·22	2·82
1884–5 to 1890–1...	2·50	2·02	2·38
1891–2 to 1897–8	2·12	1·73	2·06
1898–9 to 1904–5....	1·67	1·45	1·64

When, however, the nitric nitrogen is considered in relation to the chlorine, the average amounts of which in periods of several years closely resemble the averages in rain, there is distinct evidence of a decline in the amount of nitrates produced (Table IX).

Then, again, by selecting two years of heavy rainfall, each preceded by a year of low rainfall, indications of a marked reduction in the loss of nitrogen are obtained.

TABLE X.

Loss of Nitrogen in two years of High Rainfall and Drainage.

	Rainfall	Nitrogen per acre		
		20-inch gauge	40-inch gauge	60-inch gauge
	inches	lbs	lbs.	lbs.
1880–1	36·77	57·78	44·22	49·95
1896–7	37·24	36 62	35 77	41 40

It is not an easy matter in view of the irregularity in the Rothamsted soils to obtain a very accurate estimate of the losses actually undergone by the soil of the gauges, and this difficulty is considerably increased by the incompleteness of the analysis of the drainage during the first seven years of the experiments. The following estimate is perhaps as correct as is possible under the circumstances.

TABLE XI.

Loss of Nitrogen in the Soils of the three Gauges during the last 35 years.

Depth of soil	Nitrogen								
	In soil and rain per acre			In drainage per acre			Remaining in soil, 1905	Loss in soil	
	In soil, 1870	In rain, 35 years	Total	1870–1877 (estimated)	1877–1905 (determined)	Total			
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	per cent.
20 in	6027	175	6202	231	926	1157	5045	982	16·3
40 in	10434	175	10609	204	816	1020	9589	845	8·1
60 in.	14043	175	14218	223	892	1115	13103	940	6·7

The losses of nitrogen are, therefore, considerable, but even in the case of the 20-inch gauge between eight and nine-tenths remain. It is of course possible that fixation of free nitrogen is going on all the time, and that the soil is really losing less nitrogen than indicated by the above results. We have no complete evidence either for or against fixation[1]. It is at any rate evident that plenty of nitrifiable nitrogen still remains in the soil and that the conditions remain favourable to nitrification. Determinations of lime made from September, 1896, to April, 1898, in the drainage from each gauge show that the loss of calcium carbonate amounted in a year of normal rainfall (with, however, a low amount of drainage) to about 300 lbs. in the case of the 60-inch gauge, and somewhat less in the other gauges. This would amount to 10,500 lbs. of calcium carbonate in the 35 years, or rather more than 10 per cent. of the total estimated amount[2]. There is no doubt, however, that the losses would be greater in the early years of the experiment when the soil contained more organic matter. Unlike the nitrogen, the loss of calcium slightly increases with the depth of the soil. Rather more than one-fourth to one-third of the total lime in the drainage is required to neutralise the nitric acid present.

2. *The Amounts of Chlorine in the Drainage.*

The yearly amounts of chlorine (Table XII) in the drainage are on the whole similar to the amounts found in the rain of the corresponding years, although in years of low rainfall there may be a deposition of chlorides in the soil, and consequently low amounts in the drainage, as in the year 1879–80. But the chlorides deposited one year appear as

[1] In February, 1905, two small samples were taken with a borer from the soil of the 60-inch gauge to a depth of 9 inches. The fine soil, dried at 100°, contained 0·102 per cent. of nitrogen, corresponding with 2,448 lb. per acre. This amount deducted from the estimated amount in the soil in 1870 (see p. 379) indicates a loss of 1056 lbs. in 35 years. This agrees as nearly as can be expected with the estimate in Table XI, and makes it improbable that the soil has acquired any considerable amount of nitrogen from the air, either by fixation of free nitrogen, or by absorption of ammonia, beyond that supplied by rain. It may here be mentioned that for some years, until four or five years ago, a growth of *Nostoc* was frequently observed on the surface of the 20-inch gauge. It has been shown by Kossowitsch (*Bot. Zeit.* 1894, **52**, 97) and by Bouilhac (*Ann. Agron.* 1898, **24**, 561) that bacteria exist which in presence of *Nostoc* fix elementary nitrogen. It is, however, not established that *Nostoc* is always accompanied by this microbe; and in the present case no material amount of fixation can have taken place, as the growth was always at once removed.

[2] For full results relating to calcium in the drainage through the 60-inch gauge see *Proc. R. S.* 1905, B. **77**, 14.

additional amounts in the drainage in other years, so that the averages of several years closely correspond with the average amounts in the rain for the same periods. This is of some interest, since it makes it possible in the case of field drainage, where the amount of percolation is unknown, to calculate from the concentration of the chlorine present, both the amounts of yearly drainage and the total amounts of other constituents. This applies, of course, only to conditions of soil and climate similar to those at Rothamsted. And approximately correct estimates are only to be expected when results extending over a few years are available.

TABLE XII.

Annual Amounts of Chlorine in the Rain and the Drainage through 20, 40, and 60 inches of Soil. Gain or loss of Chlorine in the Soil.

Harvest Years, Sept.-Aug.	Rainfall	Drainage			Chlorine, lbs. per acre						
		Soil 20 inches deep	Soil 40 inches deep	Soil 60 inches deep	In rain	In drainage			Loss or gain in		
						Soil 20 inches deep	Soil 40 inches deep	Soil 60 inches deep	Soil 20 inches deep	Soil 40 inches deep	60 i
	inches	inches	inches	inches	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	
1877–8	32·65	14·72	16·44	14·84	11·97	15·54	17·95	15·81	3·57	-5·98	
78–9	41·05	24·44	26·03	24·38	15·73	19·83	21·05	19·37	-4·10	-5·32	
79–80	21·36	6·89	7·39	6·50	10·87	5·99	6·37	5·72	+4·88	+4·50	
80–1	36·77	22·38	22·84	21·26	18·06	19·00	19·40	17·49	-0·94	-1·34	
81–2	32·31	15·81	16·08	14·32	15·56	12·71	13·40	11·99	+2·85	+2·16	
82–3	34·71	20·82	21·72	19·72	17·49	17·40	19·19	17·09	+0·09	-1·70	
83–4	25·77	11·86	12·00	11·21	14·15	12·40	12·06	11·03	+1·75	+2·09	
84–5	26·78	14·82	15·14	13·98	13·32	14·83	15·57	13·76	1·51	-2·25	
85–6	31·02	17·37	18·41	16·57	12·11	12·71	14·77	13·34	-0·60	-2·66	
86–7	23·61	10·64	12·58	11·72	15·98	9·33	11·08	9·95	+6·65	+4·90	
87–8	30·50	13·96	15·58	14·67	16·99	19·75	20·96	18·10	-2·76	-3·97	
88–9	30·09	14·64	15·82	14·33	12·59	13·20	15·50	13·99	-0·61	-2·91	
89–90	27·43	13·16	13·60	12·74	10·32	11·29	12·03	11·45	-0·97	-1·71	
90–1	23·41	9·95	9·70	9·73	10·56	9·86	9·86	9·67	+0·70	+0·70	
91–2	29·68	16·50	17·43	16·47	15·54	14·59	15·69	14·67	+0·95	-0·15	
92–3	24·08	11·58	12·35	12·10	11·16	10·04	12·21	10·51	+1·12	-1·05	
93–4	29·55	13·36	14·11	14·07	18·15	18·37	17·71	16·64	-0·22	+0·44	
94–5	28·94	15·50	16·95	16·31	14·74	17·80	19·48	18·33	-3·06	-4·74	
95–6	24·37	9·84	10·75	10·35	13·33	10·40	11·36	10·98	+2·93	+1·97	
96–7	37·24	21·88	23·86	22·80	21·19	19·61	23·21	20·93	+1·58	-2·02	
97–8	19·51	5·95	6·66	6·47	16·51	7·55	8·03	7·15	+8·96	+8·48	
98–9	24·70	11·99	12·48	12·48	18·09	20·10	19·26	17·36	-2·01	-1·17	
99–1900	31·02	16·33	16·93	17·02	15·79	17·79	19·94	18·83	-2·00	-4·15	
1900–1	24·30	10·91	12·35	11·92	16·60	19·14	17·51	14·71	-2·54	-0·91	
01–2	23·26	8·75	9·32	9·44	14·80	13·99	13·99	13·32	+0·81	+0·81	
02–3	31·25	16·33	17·09	17·59	17·85	22·84	25·10	24·36	-4·99	-7·25	
03–4	31·50	17·68	17·92	18·29	19·65	14·70	17·98	18·77	+4·95	+1·67	
04–5	25·30	10·10	10·45	10·36	15·23	14·69	14·23	13·97	+0·54	+1·00	

Perhaps the most striking point in connexion with the results relating to chlorine in the drainage is the comparatively slight, although irregular, variation in the average amounts per million of water from month to month. The extremes (see Table XIII) occur in June, when

TABLE XIII.

Monthly Amounts of Chlorine in the Drainage through 20, 40, and 60 inches of Soil. Average 28 years.

1877–8 to 1904–5	Rainfall	Chlorine Per million			Chlorine Per acre			+ or − in rain (per acre)		
		20-inch gauge	40-inch gauge	60-inch gauge	20-inch gauge	40-inch gauge	60-inch gauge	20-inch gauge	40-inch gauge	60-inch gauge
	inches				lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
September..	2·35	4·53	4·53	4·31	0·86	0·85	0·75	+0·08	+0·04	+0·14
October......	3·20	4·47	4·56	4·50	1·90	1·94	1·78	−0·10	−0·14	+0·02
November .	2·84	4·77	4·86	4·65	2·33	2·44	2·23	−0·55	−0·66	−0·45
December ..	2·51	4·81	4·75	4·57	2·22	2·33	2·16	−0·33	−0·44	−0·27
January ...	2·06	4·26	4·56	4·35	1·61	1·93	1·80	+0·13	−0·19	−0·06
February ...	1·98	4·22	4·23	4·06	1·44	1·59	1·45	+0·09	−0·06	+0·08
March	1·90	5·01	5·05	4·84	1·10	1·28	1·16	+0·41	+0·23	+0·35
April	1·84	4·51	4·50	4·51	0·49	0·56	0·52	+0·50	+0·43	+0·47
May	2·13	4·75	4·57	4·50	0·58	0·63	0·57	+0·32	+0·27	+0·33
June	2·41	5·03	5·13	5·03	0·82	0·87	0·83	−0·11	−0·16	−0·12
July	2·57	4·90	4·76	4·71	0·71	0·70	0·66	−0·11	−0·10	−0·06
August	2·86	4·48	4·48	4·48	0·78	0·77	0·78	+0·03	+0·04	+0·08
Sept.—Dec.	10·90	4·67	4·71	4·54	7·31	7·56	6·92	−0·95	−1·20	−0·56
Jan.—April	7·78	4·43	4·56	4·38	4·64	5·36	4·93	+1·13	+0·41	+0·84
May—Aug.	9·97	4·78	4·74	4·69	2·89	2·97	2·79	+0·13	+0·05	+0·23
Oct.—Mar.	14·49	4·58	4·66	4·48	10·60	11·51	10·58	−0·35	−1·26	−0·33
April—Sept.	14·16	4·70	4·67	4·59	4·24	4·38	4·06	+0·66	+0·52	+0·84
Year......	28·65	4·61	4·66	4·51	14·84	15·89	14·64	+0·31	−0·74	+0·51

the drainage from the three gauges contain respectively 5·03, 5·13, and 5·03 per million of chlorine, and in February when the minimum amounts of 4·22, 4·23, and 4·06 per million are reached. Comparing the summer and winter drainage the amounts of chlorine are practically identical in the case of the 40-inch gauge and differ only by 0·1 per million in the 20- and 60-inch gauges, the higher numbers occurring in the summer drainage. Under the circumstances it is obvious that the amounts of chlorine per acre vary directly in relation to the amount of the drainage.

Comparing the average monthly amounts per acre of chlorine in the drainage with the average quantity found during the same period of 28 years in the rain it is seen that, speaking generally, the soils of the gauges lose chlorine in the winter months and gain in the summer months. In each case there is a loss from October to December, and a gain from February to May, the greater portion of the excess occurring in March, April, and May. The greatest loss is in November, when the chlorine (per acre) in the rain is highest, and the greatest gain in April (Fig. 4).

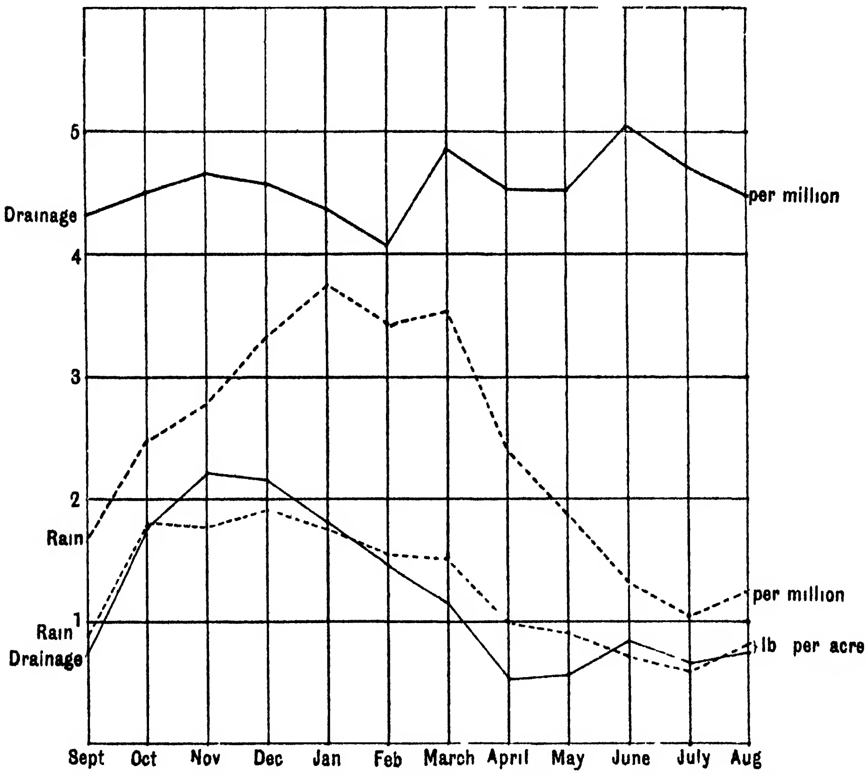

Fig. 4. Chlorine in rain and drainage through 60 inches of soil, per million and lbs. per acre. Average 28 years.

The yearly amounts of chlorine in the drainage (Table XII) are subject to great variations according to the amounts of drainage in the respective years and in that of the preceding years. In years of drought the soil may acquire several pounds of chlorine per acre from the rain (for instance, 1879–80, 1886–7, and 1897–8), whilst in wet years (1877–8, 1878–9, and 1902–3) there may be more or less considerable losses.

Calculating the total gain or loss for the whole of 28 years the following numbers are obtained:

	Chlorine lbs. per acre
20 inches of soil.........	+ 8·68
40 ,, ,, ...	−20·72
60 ,, ,, ...	+14·28

From results of determinations of chlorine in samples of soil collected in 1870 near the gauges it is estimated that the soil of the 20-, 40-, and 60-inch gauges originally contained 121, 238, and 342 lbs. of chlorine per acre respectively. These amounts seem to have been washed out of the soil during the first few years of the experiments. Frankland (6) found in samples of the drainage collected in November and December, 1870, after heavy rainfall in October, amounts of chlorine varying from 21·5 to 38·0 per million. Since 1877 the highest result obtained in the monthly drainage of the 20-inch gauge (which varies the most) has been 10·0 per million.

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BRITISH TICKS.

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THE Ixodidae have received so little consideration at the hands of British naturalists that there does not exist amongst our literature any classification of the family having pretension to accuracy or completeness. This may be sufficient to account for the fact that in 1900 when inviting correspondence through the columns of *Science-Gossip*[1], I did not receive any reply from a fellow-countryman who had made a serious attempt to study the British ticks, though I have been favoured with much kindly assistance from correspondents who had turned their attention to foreign species.

There seems no doubt that the best classification of the genera, giving descriptions of the known species, is that contained in a very carefully compiled series of articles in the *Mémoires de la Société Zoologique de France* for the years 1896–97–99 and 1902[2]. These articles were written by M. G. Neumann, Professeur à l'École vétérinaire de Toulouse, and are entitled "Révision de la famille des Ixodidés." Some of these papers are out of print, and may not fall readily into the hands of an English reader.

The diagram (fig. 2) of the various parts of a tick may assist readers in following the descriptions in this paper.

Ticks pass through four stages in their existence: the egg, the larva, the pupa or nymph, and the adult. In the larval, pupal, and adult female stages of the sub-family Ixodinae the body is enclosed by a highly distensible cuticle. The body is partly covered by a hard scutellum, or shield, on the back, and is provided with a false head, or capitulum.

[1] Vols. VII. and VIII., New Series.

[2] Vols. IX., X., XII. and XIV.

The latter carries the palpi, and the mouth organs, consisting of a hard chitinous labium or hypostome provided with a tube for the suction of blood, and armed with rows of barbs for clinging on to the flesh of the host. On each side are situated the mandibles, also called chelifers, or chelicerae. They are retractile, and doubtless serve to cut a slot in the skin to make a passage for the insertion of the labium, and afterwards to force it into the flesh of the host. For these purposes the chelifers are furnished with a series of teeth or hooks. Collectively these organs constitute the rostrum.

The adult male is similar, but he has a shield that, with the exception in many cases of a narrow margin, covers the whole of the body. The latter is incapable of being much distended by the suction of the host's blood. In the sub-family Argasinae these shields are altogether absent and distension after feeding does not take place to anything like the same extent as with the Ixodinae. In the larval stage ticks have but six legs, but in all other stages eight legs.

In adults the sexual organ is situated far forward between the haunches of the legs; behind it is the anus, usually surrounded in part by a groove, and on each side, near the fourth pair of legs, is placed a stigmal plate or peritreme for respiration, in the centre of which is the stigma. The plates are absent in the larval state. There is reason for believing that the sexual organ of the male may be either immature or obsolete in certain, if not all the species of Ixodidae, and that in such cases the sexual functions are performed by the mouth organs, all of which are inserted with the exception of the palpi[1]. The sexual orifice is absent in the larval and pupal stages. The tarsus, or last joint, of the first pair of legs is furnished with a peculiar organ (see figs. 2, 13 and 14), known as "Haller's organ," which is probably one of touch, hearing, or smell; but its function is not understood. The second pair of legs are the shortest, and the fourth pair the longest.

The life-history of a tick is sharply divided between a free and a parasitical existence. In the first state it lives absolutely without food of any sort for prolonged periods, and passes its time either in a semi-torpid condition, or else is actively occupied in searching for a host on which to establish itself. A headless female of *Ixodes ricinus*[2], lacking all the mouth organs by which feeding would be possible, survived under my observation for over a year in captivity, and was eventually lost.

[1] See Appendix, p. 425.

[2] Mentioned by me in "Louping-ill and the Grass-tick" in the *Royal Agricultural Journal* of December, 1899 (Vol. x., Part IV.). See Appendix, p. 427.

Argas persicus is similarly stated to have lived without food for three and a-half years in captivity[1]. At such times all growth is suspended, and the tick is debarred from making any advance towards metamorphosis from one stage of its existence to another.

In the parasitical states life is supported by sucking the blood of the host until the body of the tick has, unless it is an adult male, become enormously distended, and it is in this condition that these pests are generally noticed owing to their increased size. When replete, whether as larvae or nymphs, most species fall to the ground, and there remain while development is proceeding inside the distended cuticle. After a time the skin is split open, and the creature emerges with its rostrum, shield, legs and other external parts, increased in size and fully developed. The body is proportionately diminished, so that the animal's entire length is about the same as before; but the new body, being formed of a similarly distensible cuticle, is again ready for repletion so soon as another host is attacked. Adult females when distended also fall to the ground, and remain there for oviposition.

Some species never leave the host they have first found, but pass all their metamorphoses upon it. In this respect the habits of different Ixodidae vary considerably. *Ixodes ricinus* seeks a fresh host after each moult, but as yet little is known of the habits of any other British species. Mr Lounsbury, Government Entomologist at the Cape of Good Hope, informs me that the "red tick," *Rhipicephalus evertsi*, passes the first moult on, and the second moult off, the host. *R. decoloratus*, the "blue tick," never leaves the host that it has once found, after being hatched out of the egg, until, if a female, it is ready in its turn for oviposition. *Argas persicus* attacks by night, like the bed bug, a practice which may enable it to escape destruction from the beaks of the fowls or pigeons which are its usual prey, as at such times they would be asleep, or at least in a drowsy condition. Mr Lounsbury says "it has the peculiarity of undergoing an additional moult, and, what is more, when adult, alternates egg-laying with feeding, the interval being about the same as between the moults." Referring to the South African "bont-tick," *Amblyomma hebraeum*, Mr Lounsbury writes: "Females do not appear to complete their engorgement until they have mated." If this be so with *I. ricinus*, and perhaps other species, it may account for the numerous dead and half-distended specimens that may generally be found on sheep in the North of England.

[1] Referred to by C. Fuller in his *Bovine-tick Fever*, 1896, p. 8.

The length of life depends mainly on the climatic conditions, and whereas Messrs Dixon and Spreull state that *Rhipicephalus decoloratus*, the Texas cattle-tick, is only sixty days in passing the whole period of its existence, it is probable that our British species average about a year and a half, varying largely according to circumstances.

The damage done to stockowners by these pests in other countries is enormous. Mr Cooper Curtice says[1]: "Cattle-ticks cause the quarantine of eighty-one counties in North Carolina. The cattle traffic in thirteen States and the Indian Territory is seriously interfered with on account of the ticks."

Mr P. R. Gordon, Chief Inspector of Stock for the Government of Queensland, states in his Annual Report for 1898 that previous to that year no less than £44,000 had been spent in that colony in connexion with the investigations and experiments made in combating "tick," or "Texas fever" The searching character of these investigations has probably proved the salvation of stock-raising in Australia, as they resulted in the discovery by Mr C. J. Pound, Director of the Stock Institute, that inoculation by the blood of immune beasts would produce immunity in previously susceptible stock.

From Cape Colony Mr Lounsbury writes in his Report for 1899: "Heartwater," another tick-inoculated disease, "seems to have gained fresh impetus of late years, and is spreading by leaps and bounds into the Midlands." "The market value of these properties is depreciated by the infection from 30 per cent. to 60 per cent., I am reliably informed." This disease attacks sheep and goats, and is carried by a tick named *Amblyomma hebraeum*.

The following diseases are now known to be tick-conveyed, the tick acting as an intermediary host[2]:

Human Tick Fever	Man	*Ornithodoros moubata* (? *savignyi*)
Texas Fever or Redwater	Cattle	*Rhipicephalus annulatus* " *decoloratus* " *evertsi*
Heartwater	Sheep, goats, etc.	*Amblyomma hebraeum*
Malignant Jaundice	Dogs	*Haemaphysalis leachi*
Piroplasmosis	Sheep	*Rhipicephalus bursa*
Piroplasmosis	Cattle in Europe	*Ixodes ricinus* (?)

[1] "Regulations for the Control of Contagious Diseases of Live Stock, etc.," May 1st, 1900, North Carolina Department of Agriculture.

[2] See Nuttall (1904–5) *Journal of Hygiene*, Vol. IV. pp. 219—257; Vol. V. p. 237, *et seq.* *Trans. Epidermiol. Soc.* London, Vol. XXIV. pp 12—82. This author is preparing an exhaustive treatise on Ticks.

The ravages caused in Scotland and the Borders by the disease known as "Louping-ill" have been commonly attributed to the direct agency of the Grass-tick, *Ixodes ricinus*, but recent investigations negative this conclusion, except as to its being an accidental carrier of the specific bacillus[1].

That ticks may be the carriers of the germs of other animal diseases in this country is very probable.

As the study of ticks is of so much economic importance, a few hints as to the methods of collecting and preserving them may not be out of place. The object in view is usually identification of species, or investigation of the life-history of the parasite. For the former purpose the large distended females, which are generally those first noticed on the host, are of comparatively little use. The great distension of body obliterates some material characteristics and obscures others. Where these large females are observed careful search should be made for the much smaller undistended specimens, by which identification is facilitated.

Ticks of a uniform brownish colour may generally be preserved without damage in spirits of wine, but those having variety of colour should be immersed in 3 per cent. formalin. For examination and future reference I find it convenient to mount them dry in cells as microscopic objects. This keeps them clean and free from dust. Those that have been soaked in formalin must be very thoroughly washed and dried. Even then they will be found to deposit an oily dew on the slide and cover-glass. This can only be removed by remounting, which may have to be done more than once. Treated in this manner they have so far retained their colours excellently. They may also be mounted in Canada balsam as transparent objects, but so mounted they are far harder to identify, and I have found difficulty in clearing the body of its contents when preparing them in this manner after they have been much distended. Ticks may be almost instantly killed by the use of chloroform.

For the purpose of studying their life-history ticks may be kept alive for long periods in tightly corked glass bottles, but many species require to be supplied with a little very slightly damped sand and fresh moss. Provided there is enough moisture to keep the moss alive, and no more, lest the ticks become mouldy, they will survive many months. Air does not seem necessary to them. If collected when fully distended

[1] The results of the investigations of the Louping-ill and Braxy Committee of the Board of Agriculture, which are here referred to, will shortly be published in a Blue Book.

in any immature stage they will undergo metamorphosis, or when adult the females will lay eggs, in confinement.

The process of egg-laying by ticks is most remarkable, and was fully described by Mr R. T. Lewis in the *Royal Microscopical Journal* of 1892. When oviposition is about to take place, the head is depressed till it rests close against the under side of the body (fig. 4). In this attitude the end of the rostrum actually touches the genital orifice, the palpi being at the same time widely opened out. From between the head and the shield a white, perfectly transparent, delicate, gelatinous membrane is brought down over the head, which it temporarily conceals. This is attained by inflation with a transparent fluid. The end of this membrane terminates in two points, covered with a glutinous secretion. At the same time a semi-transparent ovipositor is pushed forward from the genital orifice. As the ovipositor, within which is the egg, projects, this organ turns inside out, and leaves the egg protruded at the end, lying between the two cónical points of the membrane. The ovipositor and membrane are then both withdrawn from each other, leaving the egg adhering to the glutinous surface of the latter. Owing to the withdrawal of its fluid contents the membrane collapses, and, dragging the egg forward with it, deposits it on the top of the head. Neither the legs, palpi, nor the organs of the mouth take any part in the oviposition. After the collapse of the membrane the palpi are closed, and the head is raised, by which latter action each egg is pushed further forward to the front edge of the shield, forming in time an adherent mass of eggs, which are deposited in front of the tick (figs. 1 and 5). The rough sketches shown on fig. 3, *a*, *b*, *c*, and *d*, will help to explain the process. The time occupied by a female *Ixodes ricinus* in depositing one egg was three minutes, with a further similar interval between the laying of two eggs. As the number of eggs laid is about 2,050[1], and the process continues at intervals for several days, it may easily be observed under the microscope.

It is scarcely necessary to emphasise the importance of keeping notes of the date and place where specimens are found, together with any circumstances attending their capture, especially the prevalence of disease amongst hosts infested by them.

It must be remembered that not only do individuals of all species vary much in size when fasting, but in the Ixodinae the variation is

[1] Some foreign ticks, such as *Amblyomma hebraeum*, are said to lay as many as 17,000 eggs. Fig. 1 is from a remarkable photograph by Mr C. J. Pound of female Rhipicephali (a foreign species) ovipositing.

immensely increased when distension takes place on a host. Full consideration must be given to this fact when referring to the measurements given below. The colours of distended individuals also depend entirely on the quantity of blood consumed. When the distension is complete the colour is usually a blue-black in all stages.

It is with the object of popularising the systematic study of British ticks that I venture to print the following *résumé* of M. Neumann's classification, giving copies of such of his figures as may assist in explaining the letterpress[1]. The descriptions which are in great part taken from those of M. Neumann, are confined to the more salient characteristics, and may probably suffice for identifying the sub-family and genus to which a specimen may belong. To these are added remarks on the number of known species in each genus, a description of those which have been identified in this country, a list of synonyms, and other points of interest[2]. Most of the characteristics referred to are such as may be examined readily without having recourse to any more powerful magnifier than a pocket lens.

I am indebted to the Editor of the *Royal Agricultural Society's Journal* for kindly lending me the blocks of figs. 11, 16, 17, 18, and 19, and the Editor of the *Highland Agricultural Society* for that of fig. 38, all of which were reproduced from my photographs.

CLASSIFICATION.

The family of the Ixodidae are broadly divided into two sub-families —I. Argasinae; II. Ixodinae.

I.—THE ARGASINAE.

The Argasinae are plainly distinguishable from the Ixodinae by the absence of either dorsal or ventral shields in either sex, also by the situation of the rostrum, this being placed beneath the cephalothorax, which covers it as with a hood, except in the larval state, when it is often terminal. In the pupal state it often partially projects. The palpi are plain, cylindrical, and the joints differ little from each other. Legs nearly equal in length. Colour varying from earthy yellow, or red, to dark brown. Sexual orifice situated between the two first pairs

[1] The illustrations copied are figs. 12, 15, 27, 29, 30, and 35.

[2] My remarks are based upon a series of notes contributed to *Science-Gossip* in 1900 and 1901.

of legs. In general dimensions the male is smaller than the female. Distension, after feeding, moderate.

The genera of the Argasinae are (*a*) *Argas*; (*b*) *Ornithodoros*.

GENUS *ARGAS* Latreille, 1796.

Synonym *Rhynchoprion* Hermann, 1804.

Body flat, general contour round or oval: narrower in front than behind, and larger behind the haunches of the fourth pair of legs. The sides of the body thin, or slightly thickened like a cushion. Tegument of body finely shagreened, except in certain spots which are covered with thin, roundish discs, more or less numerous and variously situated: the most important always forming a radiating series, of which the central one is longest both on the back and beneath. Eyes absent.

Of this genus M. Neumann describes eleven species, some of which are doubtful. Of these *Argas reflexus* and *A. vespertilionis* have both been found in England.

Argas reflexus Fabricius.

Synonyms: *Acarus reflexus* Fabricius, 1794; *Acarus marginatus* Fabricius, 1794; *Argas reflexus* Latreille, 1796; *Rhynchoprion columbae* Herm. 1804.

Adults: length, female from 7 mm. fasting, to 8 mm. when distended, (fig. 6); male, 6 mm. (fig. 7). The thin tegument of the female allows the brown or dark violet tint of the digestive organs to be seen, the margin always remaining yellowish (*marginatus*) and a little raised (*reflexus*) when fasting. The male is uniformly brown. The tarsi of all the legs have a prominent dorsal knob at the extremity. The hypostome is rounded at the end, and often a little dilated in the middle. Dorsal surface of the body finely shagreened. The discs are larger towards the centre and smaller and more numerous within the margin. The latter is finely and evenly folded, or wrinkled all round the body. Two of these, which are large, oval, and divergent in front, are situated near the middle line, about one-fourth of the distance from the front. They are surrounded by an interrupted circle of smaller ones. Posteriorly are others radiating from the centre, with one long middle line of this series, which almost reaches to the centre. On the ventral face is a similar well-defined radiating series. The male closely resembles the female, but the former is more narrow in front[1].

The nymph resembles the male, but is without the sexual organ.

[1] Compare fig. 7 with that of *A. persicus*, fig. 39.

The larva is round, 2 mm. in length, and has the rostrum terminal. The three pairs of legs are relatively long.

In this country this species has been found in Canterbury Cathedral, but is common abroad[1]. It is parasitical on fowls and pigeons, which it only attacks by night, hiding itself in the daytime.

Argas vespertilionis Latreille.

Synonyms.—*Carios vespertilionis* Latreille, 1796. *Caris vespertilionis* Latreille, 1804. *Argas fischeri* Audouin, 1827. *Argas pipistrellae* Audouin, 1832. *Caris vespertilionis* Gervais, 1844. *Caris elliptica* Kolenati, 1857. *Caris longimana* Kolenati, 1857. *Caris decussata* Kolenati, 1857. *Caris inermis* Kolenati, 1857. *Argas fischeri* George, 1876. *Argas pipistrellae* Westwood, 1877.

Adult. Length, 3·70 mm. by 3·78 mm. wide. Body nearly round. Dorsal surface surrounded by a margin formed of somewhat regular folds, and shagreened within. A deep transverse integumental fold behind the anus, which is situated about the centre of the body. Rostrum covered by the hood. Hypostome with four rows of teeth, and about six in each row. Palpi claviform. Legs thick, cylindrical; tarsi truncate; coxae in contact with each other (figs. 8 and 9).

Nymph. Rostrum partly exposed. Length, fasting, 1·40 mm. by 1·10 mm. Neumann gives the measurements of the nymph as 2·40 by 2·10 mm.

Larva. Similar, but rostrum fully exposed. Length, partly distended, 1·10 mm.

The above descriptions are taken from two mounted specimens kindly lent to me by Mr H. E. Freeman, being some of the original individuals found at Blyborough in 1877 when removing the church roof, and described in *Science-Gossip*[2]. It is parasitical on bats.

Genus *ORNITHODOROS*.

Body with thick sides, often densely covered with small, round, shining granules in various patterns, some deep furrows beneath. Eyes sometimes present (?).

The larva of one species, *Ornithodoros moubata* (? *savignyi*), has been shown to pass the whole of that stage of its existence in the egg, and to hatch out as a nymph[3].

[1] *Science-Gossip* (Old Series), Vol. x., 1874.

[2] *Science-Gossip* (O.S.) Vol. xiii., p. 104, and in the *Quekett Microsc. Journal*, Vol. iv., p. 228. Also (N.S.) 1901, where the illustration is called the nymph, in error, as is shown by the context.

[3] *The Nature of Human Tick Fever*, by Dr J. L. Todd, 1905.

No indigenous British species, but the following has been imported:

Ornithodoros megnini Dugès.

Synonyms: *Argas megnini* Dugès. *Rhynchoprion spinosum* Marx.

Nymph. Length, 3 mm. to 4 mm. fasting, to 9 mm. when replete.

Body brown, diamond-shaped, and with the rostrum exposed before repletion. Rostrum beneath body, and the latter squarer after distension. Palpi filiform. Legs far apart, and coxae almost entirely concealed beneath the skin. Surface of anterior half of body covered with small brown spines, replaced by whitish hairs posteriorly, which are specially numerous in the hinder margin. The stigmata are placed above, instead of behind, the fourth pair of legs. These differ entirely from the stigmal plates and peritremes usually present, and consist of cone-like projections pointing backwards. The top is truncate, and perforated by an orifice. Through this is a jointed organ, somewhat resembling the terminal joints of the palpi, which partially fills the orifice, and is furnished with three hairs at the end. It can be projected and withdrawn with rapidity. Its use is unknown. This peculiar feature, which, according to Neumann, is absent in the adult, may suffice to cause this species to be relegated to a separate genus.

The female is stated by Neumann to differ greatly from the nymph, which latter attains dimensions at least as large as the mature adult. It is in this state that it acquires most of the reserves of blood, which the female utilises to form its eggs.

Two specimens in the nymphal state were taken from the ear of an American visitor to Cambridge by Dr J. Christian Simpson[1]. They were supposed to have entered the ear when the American was camping out in Arizona. This species is well known in the States as infesting the ears of children and animals[2].

II.—IXODINAE.

The Ixodinae have the rostrum terminal, and never concealed under the body. Palpi four-jointed, of which the fourth is very short, and is situated in a hollow at the end of the third. Legs somewhat unequal in length. They are six-jointed, with two false joints, giving the appearance of having eight joints; one being on the femur and the other on the tarsus of each leg; but the latter is absent on the front pair.

[1] See his description with illustrations in the *Lancet*, April 27, 1901.

[2] See *New York Ent. Soc. Journ.* for 1898, pp. 49 to 52.

The cuticle of the body is very distensible in all stages, except in the case of adult males, and covered more or less, according to the state of distension at the time, by a dorsal shield, or scutellum. This shield seldom or never covers so much as one-half of the body, and as distension takes place it is proportionately less. In the case of males, which do not distend, the body is entirely covered, or with the exception of only a narrow margin. Stigmata are encircled by peritremes situated behind the haunches of the fourth pair of legs. The sexual orifice is situated beneath, between the haunches of the first three pairs of legs. In both sexes the orifice is half encircled by a groove, opening outwards behind (see fig. 11). There is considerable difference between the sexes, the males being usually the smaller. There are often eleven indentations on the posterior margin. The dorsal base of the rostrum of the female has two symmetrical hollows, with numerous punctuations, which are not found in the males, nymphs, or larvae; their purpose is doubtful.

The Ixodinae are chiefly parasitical on mammals, but also attack birds and reptiles. They rarely confine themselves to one species of host.

The genera of the sub-family of Ixodinae are:—

Ixodae, comprising *Ixodes, Eschatocephalus, Aponomma, Hyalomma, Amblyomma.*

Rhipicephalae, comprising *Rhipicephalus, Haemaphysalis, Dermacentor.*

IXODAE.

The Ixodae are distinguished from the Rhipicephalae by the length of the rostrum, which reaches nearly to the end of the palpi, sometimes further. The palpi are longer than broad. The presence or absence of eyes divides the genus into two groups:—*Amblyomma* and *Hyalomma* have eyes, which are placed on the marginal edge of the shield (fig. 10). *Ixodes, Eschatocephalus* and *Aponomma* have no eyes.

The form of the anal groove gives another division. In *Ixodes* and *Eschatocephalus* this groove contours the anus in front and opens behind (fig. 11). In *Ceratixodes* this groove is present in the male, absent in the female. In *Aponomma, Amblyomma,* and *Hyalomma* it contours the anus behind and is open to the front (fig. 12).

There is close affinity between *Ixodes* and *Eschatocephalus*; in fact, there is no fundamental characteristic to separate the females of the two genera; the great length of the legs, a deflected direction of the

rostrum, and the habit of living in holes and caverns, alone give presumption for placing a female specimen in *Eschatocephalus* rather than *Ixodes.* The males, however, differ entirely in the form of their palpi, which, flat and caniculated on the inner margin in *Ixodes* (fig. 13), are boldly claviform in *Eschatocephalus* and *Ceratixodes* (fig. 15).

The affinity between *Aponomma, Amblyomma,* and *Hyalomma* is greater still. The absence of eyes, as in *Aponomma,* appears a character easily distinguishable; but in some of the *Amblyomma* to find the eyes requires extreme attention, as they are neither prominent nor distinct in colour. In such cases they are probably immature or obsolete.

There is no definite distinction between the females of *Amblyomma* and *Hyalomma,* but it is otherwise with the males, which in *Hyalomma* are provided with ad-anal shields (fig. 12). These are wanting in *Amblyomma.*

(A) ANAL GROOVE ENCIRCLING ANUS IN FRONT.

(a^1) *IXODES* Latreille, 1795.

Synonyms: *Acarus* Linn., 1758; *Cynorhaestes* Hermann, 1804; *Crotonus* Dumeril, 1822.

Eyes absent. Palpi long. An ad-anal groove open or closed behind, encircles the anus in front; another long groove similarly encircles the sexual organ in front and widens behind (fig. 11). No terminal spine to the tarsi. Underside of the male covered with shields or plates. Dorsal shield of male covering the whole body with the exception of a margin. No indentations on the posterior margin. The distended female has three dorsal longitudinal grooves behind. Peritremes and stigmata circular.

Professor Neumann describes over sixty species of this genus.

Ixodes ricinus Latreille, 1804[1].

Synonyms: *Reduvius* Charleton, 1668; *Ricinus caninus* Ray, 1710; *Acarus ricinoides* De Geer, 1778; *A. ricinus* Linnaeus, 1788; *Cyno-*

[1] In the original article in *Science-Gossip* (Vol. VIII., p. 89) the name of *Ixodes reduvius* Leach, was adopted, following Neumann's classification. He now points out in his fourth Mémoire that this is an error, as Leach was describing a different parasite. The name *reduvius* should be therefore deleted, and *Ixodes ricinus* Latreille, substituted. This species is locally known as the "Grass-tick" in the North of England, and is one of the commonest British species.

rhaestes reduvius Hermann, 1804; *C. ricinus* Hermann, 1804; *Ixodes megathyreus* Leach, 1815; *I. bipunctatus* Risso, 1826; *Cynorhaestes hermanni* Risso, 1826; *Crotonus ricinus* Dumeril, 1829; *Ixodes trabeatus* Audouin, 1832; *I. plumbeus* Dugés, 1834; *I. reduvius* Hahn, 1834; *I. fuscus* Koch, 1835 (?); *I. lacertae* Koch, 1835 (?); *I. pustularum* Lucas, 1866; *I. fodiens* Murray, 1877; *Ixodes rufus* Koch; *Ixodes sulcatus* Koch; *Ixodes scuiri* Koch.

FEMALE (fig. 17). Length from about 3 mm. when fasting, to 10 mm. long by 6·50 mm. wide when fully distended. Basal joint of first pair of legs with a long spine. Legs, shield, rostrum, etc., dark brown to nearly black. Colour of body deep orange-red, showing four faint dark intestinal lines behind the shield; lighter underneath; light grey in front both above and below. Pubescent, opaque, and margined. When distending, light red to reddish-grey, or even pure white; fully distended, olive green, or dark red to black, with irregular yellow streaks on the back and sides when about to lay eggs. Sexual orifice opposite fourth pair of legs. MALE (fig. 16). Length about 2·35 mm. to 2·80 mm. Coxae of first pair of legs with shorter spine. Body dark brown to almost black, with brownish-white margin. Apparent sexual orifice opposite third pair of legs. Rostrum much shorter than that of female (figs. 13 and 14). Shield oval. Anal shield small, about one-third the length of the large ventral shield (fig. 21)[1].

NYMPH (fig. 18). Length, about 1·50 mm. fasting to 3·00 mm. when replete. Body olive-white, with four distinct brown posterior intestinal marks, also similar anterior ones; leaving a paler centre to the shield shaped like an arrow-head. When distending, opaque white to blue-black, and finally black.

LARVA. Length, 0·80 mm. fasting to 1·43 mm. distended. Body transparent, with olive-green intestinal marks; same colours as nymph when distending (fig. 19).

It is parasitical on numerous hosts, of which the favourite appear to be sheep, goats, cattle, and deer; but it is found on hedgehogs, moles, bats, etc., even on birds and lizards.

Ixodes hexagonus Leach, 1815.

Var. *longispinosus* Neumann.

Synonyms: *I. autumnalis* Leach, 1815; *I. erinacei* Audouin, 1832; *I. reduvius* Audouin, 1832; *I. crenulatus* Koch; *I. vulpis* Pagenstecher, 1861; *I. erinaceus* Murray, 1877; *I. ricinus* Mégnin, 1880.

[1] Compare figs. 21 and 22.

FEMALE (fig. 20). Length, 3·00 fasting to 11 mm. when fully replete. Coxae of first pair of legs with a moderate spine. Shield heart-shaped, punctate; body finely hirsute. Palpi short and broad. Labium shorter, and tarsi of all legs more truncate than in *I. ricinus.* Body when slightly distended drab, waxy, and semi-transparent. Rostrum, shield, legs, &c., light testaceous. MALE. Length, 2·50 to 3 mm. Red-brown, legs lighter. Shield punctate, leaving a narrow margin round the body. Genital orifice opposite the interval between the second and third pair of legs. Body elliptical, almost as large in front as behind. Spine on coxae of first pair of legs longer than in the female, but shorter than that of the male *I. ricinus.* Anal shield nearly as long as the ventral shield between the apparent sexual orifice and the anus[1] (fig. 22).

PUPA. Fasting 1·76 mm. Body light bluish-grey, margined, transparent, with four posterior large intestinal marks joined together behind the shield, and smaller ones extending to the front and sides; visible through the shield. Uniform brownish-white when distended Shield, legs, rostrum, etc., pale testaceous.

LARVA. 0·88 mm. fasting to 1·76 mm. distended. Body light, translucent, becoming dark on repletion. Shield, legs, etc., very pale testaceous. Body with very similar intestinal marks to *I. ricinus.*

This species is common, and is parasitical on various hosts, more especially on stoats, ferrets, hedgehogs, etc. It is also found on sheep, cattle, and other animals. The males are rare, and, unlike *I. ricinus*, are not generally found accompanying the female on the host. It seems possible from this fact, that this species is essentially a "kennel" tick, frequenting naturally those animals only that return nightly to a kennel, hole, or burrow, at which time sexual intercourse may take place, and that when found on other animals its presence may be considered accidental, and that in such cases propagation of the species is unlikely to occur. The point seems worthy of investigation.

Ixodes hexagonus Leach, var. *inchoatus* Neumann, described as *I. plumbeus* in *Science-Gossip* of 1899. The length of the female is only about 2·86 mm. fasting to 6·56 mm. when replete. Colour of body fasting light brownish-grey, with eight large dark triangular intestinal marks, terminating within the margin, two other small ones being nearly concealed by the shield. Margin distinct, grey. Head, shield, legs, etc., same colour as *I. hexagonus.* Coxae of first pair of legs differ, having

[1] Compare figs. 21 and 22.

no distinct spine, but sometimes a tubercle. The second and third pairs have also small tubercles. Labium shorter, with only eight barbs, as against about ten on the outer margin in *I. hexagonus*. MALE. Length, 2·52 mm. Body elliptical, deeply punctate above and below. Margin round shield wider than in *I. ricinus*. Apparent genital orifice as in *I. hexagonus*. Small spine or tubercle on coxae of front pair of legs. Anal shield long as in *I. hexagonus*. This description is taken from a solitary capture found in the North Tyne Valley in copula, intercourse being by the mouth organs, as with *I. ricinus*.

PUPA and LARVA. Similar to *I. hexagonus*, but smaller and lighter, the larva, being 0·74 mm. fasting. This tick is very abundant on the shepherds' dogs on the Border, but in no case was found on sheep. The male was not found present with the females on the host.

Ixodes tenuirostris Neumann.

The following description is taken from one of two females found on a vole at Painswick, in Gloucestershire, in 1893, kindly sent me by Mr C. J. Watkins, who also gave me photographs of a nymph and larva, evidently of the same species, from the collection of the Hon. C. Rothschild. Both the females have been mounted in balsam. The one is in my possession; the other is in the British Museum. I found two females of this species on a field vole, at Alnwick, on August 18th, 1901.

FEMALE. Length partly distended 3·78 mm. Coxae of all legs without spines or tubercles. Palpi long and narrow, second joint twice the length of the third joint. Capitulum prolonged laterally to a prominent point on each side (fig. 23), from near the ends of which spring the palpi, which are thus set widely apart at the base. Coxae of fore-legs developed to fit into the angle thus produced. Shield oval, with two posterior marginal indentations. Sexual orifice between the third pair of legs. Tarsi of fore-legs cylindrical, truncate, and with very slight indentations. Body finely and shield coarsely and sparsely punctate.

MALE (fig. 24). Length 1·83 mm. Light brown, margin lighter, nearly white. Capitulum slightly distended laterally. Palpi wide apart at the base, though in less degree than in the female. Coxae of all legs without spines or tubercles. Apparent sexual orifice opposite the space between the second and third pairs of legs. Ventral shield large. Tarsi short and truncate. Labium and palpi very short and wide.

The male was described for the first time by me in *Science-Gossip* for December, 1901. I was indebted to Mr Pocock, of the British Museum, for kindly lending me a specimen preserved in spirits, recently taken from a long-tailed vole (*Arvicola pratensis*) near Swansea. The species occurs on the short-tailed vole (*A. agrestis*), and doubtfully on the water vole.

As it has now been taken in Gloucestershire, Northumberland, and in South Wales, it must be widely distributed, and will probably prove to be by no means uncommon. This species is the most minute of the British ticks. It resembles *I. hexagonus* in general appearance, but is much smaller, and can be at once recognised by the greater width between the palpi at their base than at their extremities, which touch, and thus give the idea of grasping, the labium. All the above specimens were taken from voles. I also found a fasting nymph on a dead shrew mouse at Alnwick in July, 1902. Length 1·10 mm. Very transparent. Light testaceous mottled with brown. Shield coarsely and body finely striated above. A few strong white hairs above and below. The lateral projections of capitulum marked.

(B) ANAL GROOVE ABSENT IN FEMALE, BUT ENCIRCLING ANUS IN FRONT IN MALE.

(a^2) *CERATIXODES.*

Synonyms: *Ixodes* Cambridge, 1879. *Hyalomma* Cambridge, 1879. *Ceratixodes* Neumann, 1902.

Palpi long, convex inside and with a conical prolongation in the male, slightly caniculated and swollen at the end in the female. No eyes. Anal groove absent in the female, but present in the male. One anal and two ad-anal shields in the male. Peritremes circular in both sexes.

Ceratixodes putus Cambridge.

Synonyms: *Ixodes putus* Cambridge, 1879; *Hyalomma puta* Cambridge, 1879, female. *Ixodes borealis* Kramer and Neumann, 1883, female. *Ixodes fimbriatus* Kramer and Neumann, 1883, male.

FEMALE (fig. 25). Length fasting 3·30 mm. to 10 mm. when replete. Body oval, rounded at both ends, light grey, with numerous white hairs above and below. Shield yellowish-grey mottled, with lateral triangular margins rich brown; subtriangular in shape, and twice as wide in front

as behind, where it is rounded. Cervical grooves converging in front, then diverging and a little concave within, enclosing a raised portion: punctuations large and fairly regular. Sexual orifice opposite the second pair of legs. Sexual grooves widely separated behind. Anal grooves absent. Peritremes round. Legs and palpi light green, mottled with dark green and orange. False articulations near the middle of the tarsi of the three hinder pairs of legs. Labium orange, with two rows of teeth on each side.

MALE (fig. 26). Length 3·70 mm. Body greenish-yellow, mottled with black when alive, margins light grey. After death, body dark reddish-brown. Flat, square, and covered with both large and small punctuations. The margin divided behind into five short wide segments or festoons, on each of which is a fringe of strong white bristles. Ventral side finely punctuated, showing the same five segments which are separated from each other by the sexual and anal grooves respectively. Apparent sexual orifice opposite the space between the first and second pair of legs. Sexual grooves widely diverging behind, anal grooves parallel. Peritremes small and round. Palpi much longer than labium, third joint being as long as the first and second together, and pointed. Legs and palpi yellowish-green mottled with darker green. Labium bright orange, very short. Three front pairs of legs thick, the third being thicker than the second, and the second than the first. The fourth pair much attenuated.

NYMPH. Length 1·59 mm. to 3·50 mm. when fully distended. Colour (in spirits) brownish-yellow. Body nearly round. When fully distended nearly black, and legs dark testaceous. Shield shaped like that of the female.

This species had not been reported in England till 1901, when I received three distended nymphs found on a guillemot from Mr S. F. Harmer, F.R.S., University Museum of Zoology, Cambridge. Mr Pocock afterwards obtained a number of distended females from a dead puffin at Morthoe in North Devon. Since then a considerable number of males and females, both fasting and distended, have been taken by Mr Hewett of York, on cliffs frequented in the nesting season by guillemots, and other sea birds, at Bempton and Buckton on the Yorkshire coast. These were under small stones on the narrow ledges of cliff facing the sea, and in some cases were in copula. I have myself found a few on the Pinnacle rocks on the Farne Islands. I have also received a specimen from the Hebrides. It is widely distributed, having been found as far north as Alaska, and as far south as Cape Horn. The

male is certainly the most remarkable in appearance of the British ticks.

(a^3) *ESCHATOCEPHALUS* Frauenfeld, 1853.

Synonyms: *Haemalastor* Koch, 1844; *Sarconyssus* Kolenati, 1857.

Rostrum long; palpi claviform (fig. 15) in the male, flat and caniculated in the female. Ad-anal groove contouring anus in front and open behind. Peritremes circular. Irregular chitinous thickenings both above and below in the male. Very fine striae or parallel grooves on the female. Legs generally very long.

Seven species of this genus are described. They are mostly parasitical on bats, and inhabit holes and caverns.

One species, *E. vespertilionis*, widely distributed on the Continent, has just (January, 1906) been received by me from Mr Newstead of the Liverpool University, having been collected by him at Cefn in Wales.

Eschatocephalus vespertilionis (C. L. Koch).

Synonyms. Male. *Eschatocephalus gracilipes* Frauenfeld, 1853; *Ixodes troglodytes* Schmidt, 1853; *Sarconyssus kochi* Kolenati, 1860; *Eschatocephalus frauenfeldi* L. Koch, 1872; *Eschatocephalus seidlitzi* L. Koch, 1872; *Ixodes longipes* Lucas, 1872; *Ixodes siculifer* Megnin, 1880. Female. *Ixodes vespertilionis* C. L. Koch, 1844; *Ixodes flavipes* C. L. Koch, 1844; *Haemalastor gracilipes* Frauenfeld, 1854; *Sarconyssus flavipes* Kolenati, 1857; *S. hispidulus* Kolenati, 1857; *S. brevipes* Kolenati, 1857; *S. kochi* Kolenati, 1857; *S. flavidus* Kolenati, 1857.

FEMALE (fig. 19 *a*)[1]. Body oval. Length 4 to 6 mm. when fasting, to 6 or 8 mm. when replete. Colour when fasting from a light to an earthy yellow. A thick marginal dorsal pad or swelling extends, when fasting, half-way up the shield and terminates at the sides. Body thickly covered with whitish hairs except on the shield, which is light brown, elongated, lance-shaped and wider in the middle. Beneath, the sexual orifice is situated opposite the haunches of the third pair of legs. Rostrum often carried perpendicularly. Hypostome lance-shaped, and very pointed, with a wide base, covered with long, sharp teeth arranged in 4 or 5 rows on each side. Porous spaces well developed. Palpi very similar to those of the female of *I. ricinus*. Legs long.

MALE. Body, flat oval, dark red-brown in colour. Length 4 mm. On the back a narrow marginal pad or swelling, pointed in front, enlarged behind, extending almost to the stigmata. Tegument orna-

[1] The hypostome of the specimen figured is concealed by a piece of bat's flesh adhering to it.

mented with patterns or shields, which vary considerably in different individuals, some being altogether without them, whilst in others they are well developed. Genital orifice situated opposite the spaces between the second and third pair of legs. The grooves underneath resemble those of *I. hexagonus*, but are more parallel. Rostrum generally carried perpendicularly. Palpi club-shaped (fig. 15), wide apart at the base. Legs very thin and long, longer than in the male. The fourth pair the longest.

NYMPH Oval body, length 1 to 2 mm. Yellowish or reddish in colour. A few short bristles. Rostrum similar to that of larva, but more developed.

LARVA. Body oval. Length 0·2 mm. Yellowish when fasting, blood-red when distended. Rostrum not inflected, otherwise almost resembling that of the female, but the hypostome has only 2 rows of teeth on each side.

The specimens sent me by Mr Newstead consist of two partly distended nymphs and one fasting female, all taken feeding on the Lesser Horseshoe Bat (*Rhinolophus hipposideros*) from a cave at Cefn, North Wales, on April 4th, 1896, but these were not examined until now[1]. This is the first time this species has been reported in this country, though the probability of its occurrence was mentioned by me in my notes to *Science-Gossip* in 1901.

The above descriptions are extracted from those of Neumann.

(C) ANAL GROOVE ENCIRCLING ANUS BEHIND.

(b^1) *APONOMMA* Neumann, 1899.

No eyes. Base of rostrum generally pentagonal; palpi long. Body of male either wider or nearly as wide as long; beneath naked. Dorsal shield covering the whole body, and generally with green metallic marks. The shield of the female shorter and scarcely any longer than wide, ordinarily marked with three green metallic spots in a triangle.

This genus is exotic, and it is almost exclusively parasitical on snakes and saurians. Twelve species are described; but none are British.

(b^2) *AMBLYOMMA* Koch, 1844.

Synonym: *Ixodes* Latreille, 1795.

Eyes usually flat and but little apparent; sometimes brilliant; placed on the outer edge of the shield. Rostrum long. Anal groove

[1] Two other females found at the same place on Dec. 2nd, 1905, by Mr Oldham of Knutsford are deposited at the British Museum.

open in front, joining the sexual grooves. Dorsal shield often marked with coloured designs. No ad-anal shields on the male. Peritremes generally triangular, with rounded angles. Eleven marginal posterior indentations nearly always present, especially in the male.

Professor Neumann describes no less than 86 species of *Amblyomma*, mainly from tropical and sub-tropical climates. One species, *A. hebraeum*, known at the Cape as the "bont" or variegated tick, is the carrier of "heartwater" in sheep, which Mr Lounsbury says "is gradually rendering the splendid veldt of the infected districts useless for sheep farming." Not any British species.

(b^3) *HYALOMMA* Koch, 1844.

Eyes generally round and brilliant (fig. 10), sometimes flat and little noticeable. Rostrum long. Anal groove open in front, joining the sexual groove with another extending from the anus to the posterior margin (fig. 12). Body elongated oval. Colour brown, more or less dark. The male has two pairs of ventral shields, two of which are ad-anal and large, with two others outside, added to which are often two accessory ones, or lamellae, behind the ad-anal shields (fig. 12).

Only three species are described by Professor Neumann, one of which—*H. aegyptium* Linn.—is known at the Cape as the "bont-legged tick," where it attacks small stock and ostriches, as well as cattle and horses, and is considered second only to the "bont tick" as a pest to farmers. It is known probably all over Africa and the greater part of Asia. No less than thirty synonyms are given for this species, showing the great confusion there has been in the nomenclature of ticks. No British indigenous species is known, but one, *H. syriacum*, has been taken on imported tortoises.

Hyalomma syriacum Koch.

Synonym: *Hyalomma affine* Neumann, 1899.

FEMALE. Length, fasting, 6 mm., when distended up to 13 mm.; shield oval, and but little longer than wide, each anterior angle prolonged to nearly half way up the palpi; punctuated sparsely but deeply; eyes small; body reddish-brown. Two very minute dorsal spiracles behind the shield. Coxae of front legs divided with two blunt spines or tubercles; the other haunches with two small tubercles at the outer edge of each. Tarsi short and thick, and suddenly attenuated at the end, which in the three posterior pairs is furnished with a small hook.

MALE. Length, 6 mm.; shield, reddish-brown, bare, anterior angles projecting little; grooves at the neck short and deep, none at the sides; punctuations sparse, equal, and large; underside reddish-brown, sometimes yellow; anus a little behind the orifice of the stigmata; anal shields wide and short; peritremes short and comma-shaped (fig. 12).

Mr Pocock mentions this tick as having been found at Feltham in Surrey, and another was sent me by Mr F. Noad Clarke. The latter was a distended female, which he had exhibited at the South London Entomological Society in June, 1899. Others taken from tortoises imported from abroad have been received by me.

RHIPICEPHALAE.

Synonym: *Conipalpi* Canestrini.

The Rhipicephalae are characterised by their palpi, which are short and more or less conical or subtriangular—not, or but slightly, longer than broad (fig. 27). The upper face of the base of the rostrum is triangular and elongated transversely in *Haemaphysalis* and *Dermacentor*, whereas in *Rhipicephalus* it is hexagonal, and in consequence is provided with salient lateral angles. The underside of the male is unprovided with shields in *Haemaphysalis* and *Dermacentor*, whereas *Rhipicephalus* has two to four symmetrically disposed at the sides of the anus (fig. 29). The absence of ventral shields is almost always compensated for in *Dermacentor* by the great development of the haunches of the fourth pair of legs (fig. 28). *Haemaphysalis* is distinguished, independently of the absence of ventral shields in the male, by the absence of eyes, and by the form of the second joint of the palpi, which in both sexes makes a lateral projection more or less marked (fig. 30).

(c) *HAEMAPHYSALIS* Koch, 1844.

Synonyms: *Rhipistoma* Koch, 1844; *Gonixodes* Dugès, 1888; *Opistodon* Canestrini, 1897.

No eyes; base of rostrum in a rectangle, twice as wide as long. Palpi conical, second joint having a strong conical lateral projection (fig. 30). Peritreme round, or shaped like an abbreviated comma. No shields on ventral face of male. Coxae of first pair of legs not bifid, those of the fourth pair of normal size in the male. Colour uniform brownish.

Of this genus twenty-two species are described from Asia, Africa, Europe, and America, one of which, *H. punctata*, is British.

Haemaphysalis punctata Canestrini and Fanzago, 1877–8.

Synonyms: *Haemaphysalis sulcata* Canestrini and Fanzago, 1877–8; *Rhipicephalus expositicius* Koch, 1877; *Haemaphysalis peregrinus* Cambridge, 1889; *Herpetobia sulcata* Canestrini, 1890.

FEMALE (fig. 31), fasting, 3·44 in length to 12 mm. when replete. Dorsal shield deeply indented in front to encompass the base of the rostrum. Colour reddish-brown, when replete of a leaden grey, which turns to a deep red-brown in alcohol. Rostrum, shield, and legs always brownish. The body above and below punctuated finely and regularly all over. Sexual orifice opposite the coxae of the second pair of legs in both sexes. Shield coarsely and regularly punctate. Peritremes whitish and nearly round. Labium furnished with numerous very small teeth, arranged in five rows on each side. Palpi a little longer than the labium, the first joint short and narrow, the second and third much widened on the dorsal face. Legs comparatively short, coxae with a wide, short, blunt spine; tarsi short and terminated with a spur, which is small on the first pair.

MALE (fig. 32). Length, 3·10 mm. Body rather narrow, reddish-brown or yellowish. Dorsal shield covering nearly the whole body; cervical grooves deep, short and wide in front; numerous punctuations over its whole surface. Eleven indentations on posterior margin of body; peritremes lighter in colour, large, and somewhat comma-shaped. The three anterior pairs of legs with a short spine on the haunches; the fourth with a very long one directed backwards, and being at least as long as the haunch.

NYMPH. Length, 2·50 mm. to 3·00 mm. Body oval, varying from light yellow to dark red-brown. Dorsal shield rounded, with a few punctuations, otherwise like that of the female. Ventral face like the female, but the sexual orifice nearly obsolete. No spur on the tarsi.

LARVA. Body short, oval. Length, 1·20 mm.

This species is somewhat widely distributed, but is not common anywhere. The specimens taken are never very numerous. It is found on sheep, especially behind the ears; on goats, cattle, horses, etc. British specimens were sent to me by Mr Pocock, taken from a hedgehog at Dungeness, consisting of a male and distended female. I have received others taken from sheep in England, but locality not stated.

(d^1) *RHIPICEPHALUS* Koch, 1844.

Synonyms: *Acarus* Linn., 1758; *Ixodes* Latreille, 1795; *Phauloixodes* Berlese, 1889; *Boophilus* Curtice, 1890.

Eyes distinct. Base of rostrum wider than long, hexagonal on the dorsal side, forming a prominent angle at each side. Palpi short, wide (fig. 27). Coxae of the first pair of legs with two spines, usually strong. Peritremes of female in form of a short comma, generally long in the male. The male has one or two pairs of ventral shields; one pair placed on each side of the anus, triangular, sometimes rectangular, large; a second pair, if present, smaller and placed outside.

M. Neumann describes twenty-three species of this genus, most of which are African. It is to some of these that is to be attributed the immense damage to cattle already referred to, which is caused by carrying the microbes of the disease known as "tick fever," "Texas fever," etc., from diseased to healthy animals.

In the Cape Colony *R. decoloratus*, called the "blue tick," and *R. evertsi*, called the "red tick," are best known as such; in the Southern States of North America a closely allied species, *R. annulatus*, is the chief cause of the disease, which in Australia is represented by a slightly different form named *R. australis* by Mr Fuller. No British species is known; but one, *R. sanguineus*, is so widely distributed that there is every possibility of its occurring in England. It is found not only in France and the south of Europe, but in Asia, Africa, America, and Australia.

(d^2) *DERMACENTOR* Koch, 1844.

Synonyms: *Ixodes* Latreille, 1795; *Pseudixodes* Haller, 1882.

Eyes present. Base of rostrum wider than long, rectangular on the dorsal face. Palpi short and thick. Peritremes shaped like a short comma. The ventral side of the male has, like the female, no shields. Haunches of the first pair of legs bidented in both sexes; those of the fourth in the male greatly enlarged (fig. 28). Dorsal shield generally ornamented with various designs.

Seventeen species of this genus are described. One only is British.

Dermacentor reticulatus Fabricius.

Synonyms: *Acarus reticulatus* Fabricius, 1794; *Ixodes reticulatus* Latreille, 1804; *Cynorhaestes pictus* Hermann, 1804; *I. marmoratus*

Risso, 1826; *Ixodes pictus* Gervais, 1844; *Dermacentor reticulatus* Koch, 1844–47; *D. albicollis* Koch, 1844–47; *D. pardalinus* Koch, 1844–47; *D. ferrugineus* Koch, 1844–47; *Ixodes holsatus* Kolenati, 1857; *Pseudixodes holsatus* Haller, 1882; *Haemaphysalis marmorata* Berlese, 1887; *Acarus marginatus* Sulzer; *Crotonus variegatus* Duméril, 1829.

FEMALE (fig. 33). When fasting, 3·86 mm. long by 2 mm. wide. Body depressed, larger behind. Colour reddish-brown. Shield very large, extending to the level of the third pair of legs, punctuated with a few large and many small punctuations. Colour milky-white, variegated with reddish-brown. Sexual orifice is opposite the coxae of the second pair of legs. Sexual grooves near together in front, rapidly diverging behind the haunches of the fourth pair, and terminating between the second and third festoons on the posterior margin of the body. Peritreme comma-shaped, short, and rounded. Coxae of front legs deeply bifid, the others with a moderate spine. A strong claw at the end of the tarsi of the three posterior pairs of legs, very small in the front pair. Length when replete up to 16 mm. Colour light brown. When depositing eggs, mottled with dark brown above and beneath. Legs brown.

MALE. Very like female (fig. 34). Shield reddish-brown, variegated with milky-white pattern; in front this takes nearly the appearance of the shield of the female, margined by a white border behind. Coxae of the fourth pair of legs three times the size of the third. Palpi having on the second joint a sharp spine pointing backwards (fig. 35), which is less pronounced in the female. Length 4·20 mm.

I am not aware that the nymph or larva have been described.

This species varies very much in individuals, both in shape and colouring. It occurs in England occasionally on sheep. Specimens have been sent to me by Mr Pocock which were found on sheep at Revelstoke in Devonshire. It is widely distributed in Europe and Asia. It also attacks cattle, deer, goats, roe-deer, and even man. Mrs Richardson stated that in March, 1902, this species was so numerous in her garden at Stoke House, Revelstoke, as to be a nuisance to those gathering flowers. It is most probably an imported species that has become acclimatized, in which case, as it is hardy and active, it is likely to become widespread and troublesome.

TABULAR SYNOPSIS.

The following is a short tabular synopsis of the foregoing classification of the Ixodidae:

I. Rostrum concealed beneath the fore-part of the body, except in the immature states; no dorsal or ventral shields,—

ARGASINAE.

(*a*) Body flat with thin edges, finely shagreened and punctuated, narrower in front. No eyes . . . . *Argas*

(*b*) Body with thick sides, often densely covered with small, round, shining granules in various patterns. Eyes sometimes present[1]. *Ornithodoros*

II. Rostrum terminal. Body more or less covered with a dorsal shield. Considerable difference generally between the sexes. Dorsal base of the rostrum of female with two symmetrical hollows finely punctuated, which are absent in males, nymphs, and larvae.

IXODINAE.

(A) Rostrum and palpi longer than broad (fig. 11).

(*a*) Anal groove contouring anus in front (fig. 11). No eyes.

(a^1) Palpi caniculated in both sexes . . . . *Ixodes*

(a^2) Palpi claviform, not caniculated in the male. Anal groove absent in the female . . . . *Ceratixodes*

(a^3) Palpi claviform, not caniculated in the male (fig. 15). Legs very long. Anal groove present in both sexes . . . . *Eschatocephalus*

(*b*) Anal groove contouring anus behind (fig. 12).

(b^1) No eyes. Ad-anal shields . . . . *Aponomma*

(b^2) Eyes present (fig. 10). Males have no ad-anal shields. *Amblyomma*

(b^3) Eyes present. Males have ad-anal shields (fig. 12) . *Hyalomma*

(B) Labium and palpi short and more or less conical; not, or very little, longer than broad.

RHIPICEPHALAE.

(*c*) No eyes nor ventral shields in the male. Rostrum rectangular; second joint of palpi with lateral projection (fig. 31) . . *Haemaphysalis*

(*d*) Eyes present.

(d^1) Rostrum with salient angles. Either two or four shields at the side of the anus of the male (fig. 29) . . . . *Rhipicephalus*

(d^2) Rostrum rectangular. No ad-anal shields, but usually a great development of the coxae of the fourth pair of legs in the male (fig. 30) . . . . *Dermacentor*

[1] This is denied by Dr Marx in *Proceedings of Entomological Soc.*, Washington, Vol. II., No. 2, 1892.

APPENDIX.

PAIRING OF SEXES.

THERE are considerable doubts as to the method of sexual intercourse in the different genera of the *Ixodidae*. Dr Marx writes "that the orifice of the oviduct in the matured female and that of the sexual organs of the male are situated very close to the insertion of the capitulum[1]."

Dr Cooper Curtice writing of the cattle tick (*Rhipicephalus annulatus*) says, "The external genitals which appear in the adults are very similar in each sex, and occur between the bases of the second pair of legs[2]"; and again, "The male places himself in copulation, belly to belly with the female, attaches to the host by his beak, and winds his legs around those of the female, thus bringing their external genitals in contact[3]."

Others have held the same view, and as recently as last November Dr Todd referring to *Ornithodoros moubata* (?) says, "In coitus the male lays hold of the posterior margin of the female, and turning on his back, crawls forward beneath the female, until the genital pores are in opposition. Pairs are often formed and remain for hours *in coitu*[4]." One writer goes so far as to assert that the tail-like projection in *Rhipicephalus annulatus* is a penis!

It is certain, notwithstanding, that in the case of several of the species of *Ixodidae*, insertion of the mouth organs of the male into the orifice of the female takes place at the time of sexual intercourse. In proof of this I have found spermatozoa in the females of *I. ricinus* immediately after pairing effected in this manner (fig. 36)[5]. A similar manner of pairing has been observed by me in the case of *I. hexagonus*, and with *Ceratixodes putus*, which last observation has been confirmed by Mr Hewett of York. This method of intercourse seems to have been noticed by earlier observers. C. L. Koch in his *Uebersicht der Arachnidensystems*, part IV. page 10 (1847), says, literally translated, "I have

[1] *Proceedings of Ent. Soc.*, Washington, Vol. II., No. 3, p. 273, 1892.

[2] "About Cattle-ticks," by Cooper Curtice, M.D., *Journal of Comparative Medicine*, Jan., 1892.

[3] *Agricultural Gazette*, N. S. Wales, July, 1896.

[4] *The Nature of Human Tick Fever in the Congo Free State*, Nov., 1905. Liverpool School of Tropical Medicine, Memoir XVII.

[5] In this illustration two males are shown, one *in coitu*, the other waiting.

already in the preliminary treatise of which I have made mention alluded to the fact that, according to the observations of the celebrated naturalist De Geer, large ticks have been found that have a small tick attached to their ventral surface with its proboscis sunk into an aperture in the body of the larger. This condition, in which ticks are frequently found, is nothing but coition." Unfortunately no particular species of ticks are mentioned. Mr Lounsbury of the Department of Agriculture, Cape Colony, confirms these observations with regard to *Ixodes pilosus*, *Amblyomma hebraeum*, known in Cape Colony as the "bont tick," *Rhipicephalus evertsi*, the "red tick," *R. decoloratus*, the "blue tick," *Ornithodoros savignyi*, and *Argas persicus*. He also kindly sent me in 1902 spermatozoa taken from the females, after copulation, of *R. evertsi*, *R. decoloratus*, and *A. hebraeum*.

Since these have been noted in such widely different species and by such a careful observer, it seems more than probable that the habit is universal amongst the *Ixodidae*.

Mr R. T. Lewis[1] drew attention to two organs at the base of the hypostome, which if examined immediately after forcibly separating the male from the female, "presented the appearance of flexible semi-transparent tubular papillæ, which conveyed the impression to my mind that here possibly were the organs by means of which actual impregnation took place."

Dr Nuttall, however, to whom I am indebted for most valuable assistance, is of opinion that the insertion of the rostrum by the male is merely for the purpose of holding on to the female, and that the external male sexual organ is not obsolete. He considers that the spermatophores must be remitted therefrom and be in some way passed forward to the vulva, possibly by a mechanism analogous to the ovipositor of the female.

Ticks of different species vary in their habits when pairing. The males of *I. ricinus* are only to be found *in coitu* with distended females on the host. At the same time virgin males and females may be collected separately, but never in intercourse, from rushes or coarse herbage.

Immediately on being confined together in a bottle which is warmed in the pocket, pairing takes place, and usually continues for some hours. I found that if prematurely separated no sperms had passed from the male to the female.

[1] *Quekett Microscopical Society Journal*, October, 1900.

The male of *R. decoloratus* also seeks the female and remains *in coitu* several days[1]. (Lounsbury.)

The habits of *A. hebraeum* are quite different. The male first establishes himself on the host, and after he has been affixed several days he becomes a source of attraction to the females. These latter will surround him and fight amongst themselves to secure him. A male remained attached to a host almost a full year. (Lounsbury.)

SPERMATOZOA.

The spermatozoa of *Ixodes ricinus* are shaped as shown in Fig. 37. I have failed to observe any movement in them. They are usually, but not always, accompanied by a very fine worm-like body about half the length of the spermatozoon. This takes a darker stain with haematoxylin than the larger body, from which it becomes easily separated by pressure. This darker body Dr Nuttall considers to be undoubtedly nuclear. Mr Lounsbury writing in 1902 said, "The sperms vary in shape in the different species. There is no doubt about their being sperms. They do not occur in the males of *hebraeum* or *decoloratus* until these have been feeding some days and are ready for females. Of this I am positive from the examination of much material. The prettiest feature is finding them in the females. By carefully removing the whole dorsal skin, and washing out the contents of the digestive tract of fully engorged females, the forming ovaries are easily placed, and between them in the shape of a rotund, dense, white body is the receptaculum containing the sperms. It has a tube leading to the oviduct. When this is cut the sac may be removed entire and burst under the microscope when the myriads of sperms fly out. The sac is quite visible to the naked eye. I have seen several in *decoloratus* and *hebraeum*. Of course there is only one sac in a female. By carefully opening *hebraeum* males, I have found what I take to be the testes. At least I can get out a pair of bodies which swarm with sperms."

HEADLESS FEMALE.

The remarkable vitality of the headless female of *Ixodes ricinus*, referred to on page 401, is worthy of further notice. A reproduction of a photograph of the creature (fig. 38) is given for comparison with that of an ordinary female of the same species, shown by fig. 11, with the

[1] *Cape Agricultural Journal*, Nov. 24, 1898.

mouth organs complete. That such a deformed individual could survive at all seems wonderful. It will be seen that beyond a slight prominence, no vestige of any capitulum or mouth organs was present. This individual proved beyond all question the power of a tick to live many months without food of any sort.

Argas persicus Fischer de Waldheim, 1823.

As this species has often been mistaken for *Argas reflexus*, a figure (39) of the male is here given for comparison with that of the male of *reflexus* (fig. 7). The chief and characteristic differences are the wrinkled margin of *A. reflexus* as compared with the discs on that of *A. persicus*, and the prominent knobs on the tarsi of the former species, shown clearly in fig. 6 of the female. These differences are similar in both sexes.

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Fig. 1.
Female ticks ovipositing

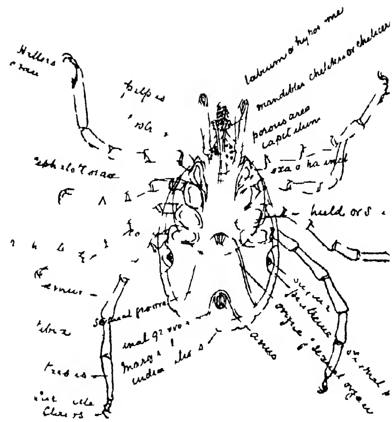

Fig. 2.
Diagram

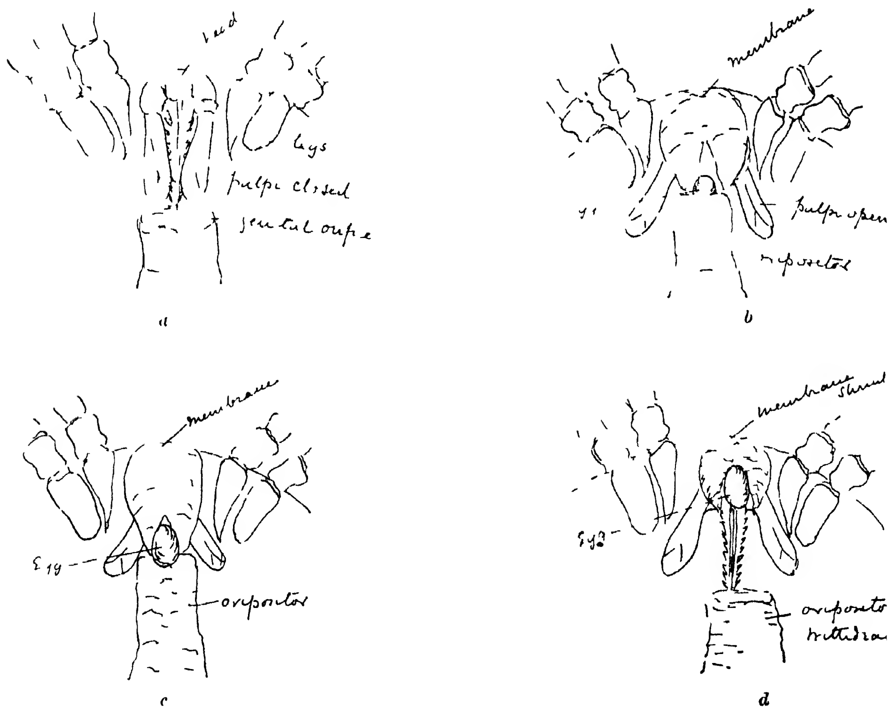

Fig. 3.
Method of oviposition

Fig 4
Ixodes ricinus 6
Fully distended and about to lay eggs

Fig 5
Ixodes ricinus ♀ 2
Ovipositing

Fig 6
Argas reflexus . 10

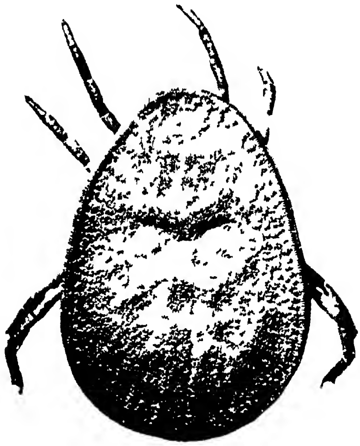

Fig 7
Argas reflexus ♂ × 10

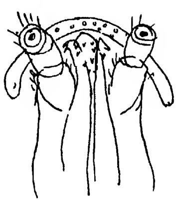

Fig. 9.
Argas vespertilionis Rostrum enlarged

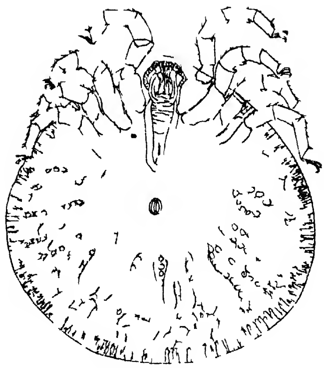

Fig 8
Argas vespertilionis × 13

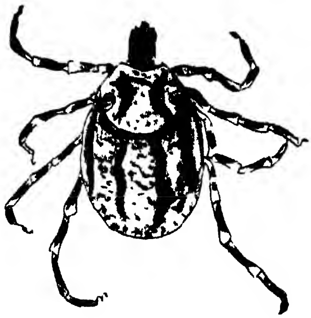

Fig. 10.
Hyalomma, shewing eyes on margin of shield

Fig. 11.
Ixodes ricinus, ♀. ×9.

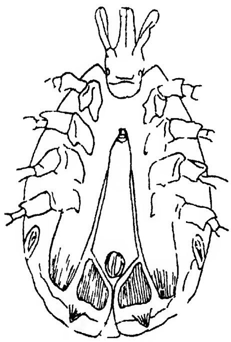

Fig. 12.
Hyalomma shewing anal groove and plates

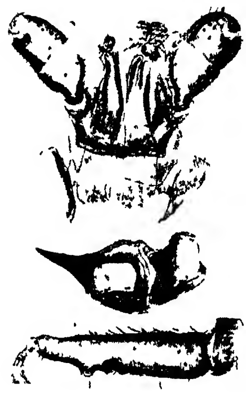

Fig. 13.
Ixodes ricinus ♂.
Rostrum, coxa and tarsus of fore-leg

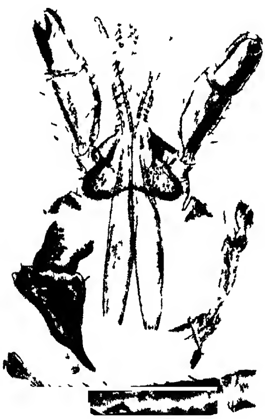

Fig. 14.
Ixodes ricinus, ♀ Coxa, caruncle and tarsus of fore-leg.

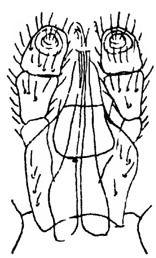

Fig. 15.
Eschatocephalus Rostrum of male.

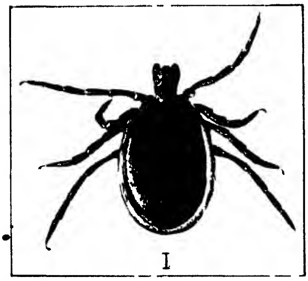

Fig. 16.
Ixodes ricinus ♂ ×12

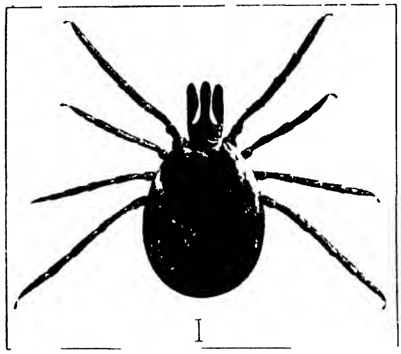

Fig 17.
Ixodes ricinus, ♀. ×12

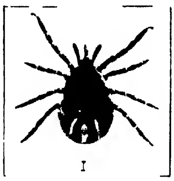

Fig 18
Ixodes ricinus nymph ×12

Fig 19
Ixodes ricinus larva ×12

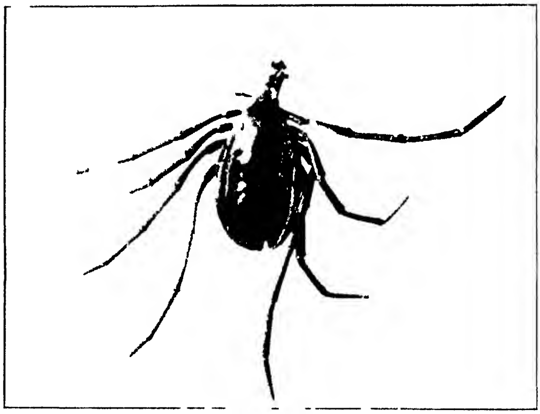

Fig. 19 a.
Eschatocephalus vespertilionis, ♀ ×7.

Fig. 20.
Ixodes hexagonus, ♀. ×6.

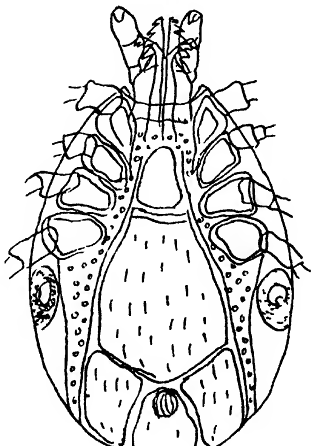

Fig. 21.
Ixodes ricinus, ♂ ×28.

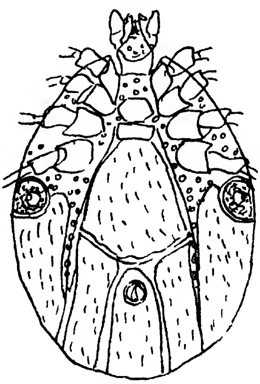

Fig. 22.
Ixodes hexagonus, ♂. ×24.

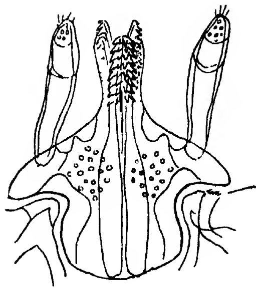

Fig. 23.
Ixodes tenuirostris, ♀.

Fig. 24.
Ixodes tenuirostris, ♀. ×24

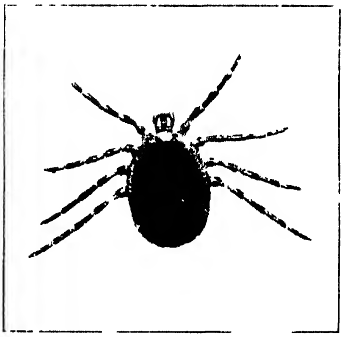

Fig. 25.
Ceratixodes putus, ♀. 7

Fig. 26.
Ceratixodes putus, ♂. ×7.

Fig. 27.
Rostrum of Rhipicephalus.

Fig. 28.
Dermacentor reticulatus, ♂. ×10.

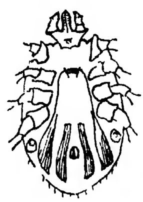

Fig. 29.
Rhipicephalus, shewing anal shields of male.

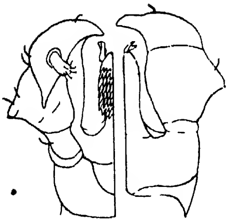

Fig. 30.
Haemaphysalis, palpi of male

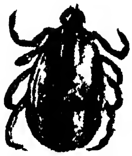

Fig. 31

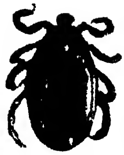

Fig. 32.

Haemaphysalis punctata ×7

Fig. 33.
Dermacentor reticulatus, ♀. ×10

Fig. 34
Dermacentor reticulatus, ×10

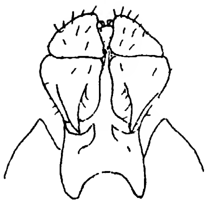

Fig. 35
Dermacentor reticulatus
palpi of male

Fig. 36.
Ixodes ricinus ×3
in coitu

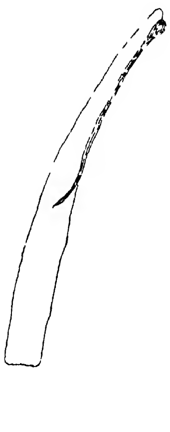

Fig. 37.
Spermatozoon of
Ixodes ricinus.

Fig. 38.
Ixodes ricinus, headless female ×6.

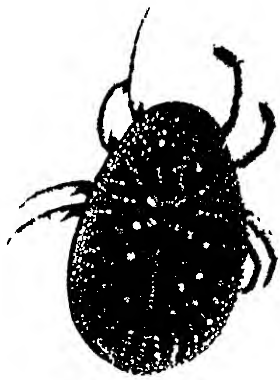

Fig. 39.
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CITRATE SOLUBILITY OF PHOSPHORIC ACID IN FERTILIZERS.

By JOHN K. S DIXON,

Chemist with Henry Richardson and Company, York.

FROM time to time treatment with solutions of ammonium citrate and citric acid of various strengths has been advocated for the determination of the available phosphoric acid in manures, but up to the present time has been applied to mineral manures almost exclusively. The action of these solvents on fertilizers containing organic matter has been so little enquired into that the writer has been led, on the suggestion of Messrs Henry Richardson & Co, to undertake the investigations which form the basis of the present communication.

The effect of ammonium citrate on bones and various other fertilizers has been investigated in America by Huston and his colleagues who found that the normal tricalcium phosphate as it exists in bones and similar preparations is dissolved by ammonium citrate solution[1]. Their results, however, are not of great value, since the treatment with citrate solution was in most cases limited to half-an-hour and in no case exceeded 10 hours.

Wagner and Maercker compared the solubilities of bone-meal and basic slag in citric acid solutions, and found that half-an-hour's treatment extracts more phosphoric acid from slag than from bones, but when the time of action is prolonged to more than five days the greater proportion is obtained from bone-meal[2].

Methner remarks that it is strange that the superiority of the phosphoric acid in bone-meal over that in basic slag for manuring purposes is not indicated by analytical results, for on using Wagner's method, the percentage of the total P_2O_5 dissolved was less in the case

[1] Wiley. "Report on Fertilizers to Indiana State Board of Agriculture, 1882." *Proceedings of the Association of Official Agricultural Chemists.* Atalanta, 1884, &c.

[2] Hoffmeister. *Landw. Versuchs. Stat*, 1898, 50, 363.

of bone-meal than in the case of basic slag[1]. This he finds to be due to the fact that the citric acid must be in a definite ratio to the phosphoric acid, which in the case of a slag with 16 per cent. P_2O_5 was 100 : 8. This ratio must also be maintained in treating the bone-meal which contains 30 per cent. P_2O_5. By using 2·5 grammes of bone-meal instead of 5 grammes and following the same method Methner claims that satisfactory results were obtained.

L. Gebek investigated the solubility of the phosphoric acid of bone-meal in Wagner's citric acid solution, and found that this quantity depended in some measure on the fineness of grinding. He also showed that the phosphates of bone-meal are soluble to a much less extent after ignition and also after the gelatin has been extracted from the substance by steaming, than they were in the original material[2]. Gebek concludes that only a small portion of the phosphoric acid of bone exists as tricalcium phosphate, and he suggests that the bulk exists as dicalcium phosphate, the remainder being in the form of an organic tribasic phosphate. On ignition the organic base would be destroyed, and lime would fill its place, forming tricalcium phosphate, thus reducing the solubility in citric acid.

For the purpose of the present investigations a series of manures was selected representative of the more common fertilizers which are added to the soil with the object of supplying phosphoric acid in a form slowly attacked by the soil water. In every case the sample used for the analyses may be regarded as thoroughly representative of each material as supplied in bulk to farmers

The solvent effect on each sample of the following six solutions has been compared:

(a) *Alkaline ammonium citrate*[3] as recommended by Petermann in his revised method of estimating citrate-soluble phosphoric acid in superphosphates. The solution is prepared by adding 50 c.c. ammonia of 0·92 specific gravity to a litre of neutral ammonium citrate of 1·09 specific gravity.

(b) *Neutral ammonium citrate*[4] of 1·09 specific gravity as formerly recommended by Petermann.

(c) *Acid ammonium citrate*[5] as recommended by Wagner for

[1] Methner. *Zeits. angew. Chem.*, 1901 [6], 184–185.

[2] L. Gebek. *Zeits. angew. Chem.*, 1894, 193–197.

[3] Publication of the *Station agronomique de l'État de Gembloux. Landw. Versuchs. Stat.* **50**, 171, (1897).

[4] *Ibid.*

[5] *Chem. Zeit.*, 1886, 19, 37, and 1887, 905.

superphosphates: viz. a solution containing 3 per cent. citric acid as neutral ammonium citrate and 0·2 per cent. as free acid.

(*d*) 2 *per cent. citric acid*[1] as recommended by Wagner for basic

(*e*) 1 *per cent. citric acid*[2] as recommended by Dyer in analysis of soils.

(*f*) 0·1 *per cent. citric acid*[3] as recommended by Hughes.

In the cases of solutions (*a*) and (*b*) the treatment was in accordance with the directions of Petermann, viz., in method (*a*) the mixture is allowed to stand for 15 hours at the ordinary temperature and then for one hour at 40° C., whilst in method (*b*) the preliminary 15 hours' standing is omitted.

In all other cases the mixture was allowed to stand 18 hours at the ordinary temperature with violent agitation at intervals, this treatment corresponding, in the experience of the writer, with the half-hour's shaking commonly recommended.

In all the analyses the proportion of fertilizer to solvent was the same, viz., 100 c.c. of solvent per 1 gr. of fertilizer.

The substance was weighed into a mortar, triturated with the solvent and transferred to a measuring flask in which the digestion was carried out.

The percentage of phosphoric acid in the citrate extract after filtration was estimated by the citrate method. It is well known that this method is not wholly satisfactory in the ordinary course for solutions containing a low percentage of P_2O_5, or in presence of much organic matter. This difficulty may be overcome, however, as demonstrated by Wiley, and amply verified by the writer, by adding to the solution previous to precipitation with magnesia mixture a definite volume of phosphatic solution of known strength, a corresponding deduction from the weight of magnesium pyrophosphate obtained being made[4]. This procedure was adopted with the samples containing less than 15 per cent. P_2O_5.

The citrate and magnesia mixture were added simultaneously in

[1] Wagner. *Landw. Versuchs. Stat.*, 1895.

[2] *Journ. Chem. Soc.*, March, 1894.

[3] *Journ. Soc. Chem. Ind.* xx., p. 325 (April, 1901). According to Hughes' method, the proportion of manure to solvent is made 1 : 1000, and the time of digestion 24 hours. In the present investigations the above proportion was made 1 : 100, and the time 18 hours in order to obtain uniformity between this and the other two citric acid methods.

[4] Runyan and Wiley. Paper presented to the Washington Section of the American Chemical Society, 1895.

order to avoid the precipitation of silica; for Wagner showed that citrate extracts (particularly after long standing) have a tendency to separate silica when the alkaline citrate is added before the magnesia mixture, and that this does not occur when added together[1]. The citrate-magnesia mixture is prepared by dissolving citric acid (200 grammes) in 20 per cent. ammonia and diluting to one litre with the same ammonia. The solution is then mixed with an equal bulk of magnesia mixture.

In the tables the results are given in two columns, (1) the absolute percentage of citrate soluble P_2O_5 in the sample, (2) the percentage of the total P_2O_5 which has been dissolved—*i.e.* $\frac{\text{citrate soluble } P_2O_5}{\text{total } P_2O_5} \times 100$, the latter often being referred to as the 'solubility.'

The data are so conflicting at the present stage of investigation that it is impossible to do more than draw attention to apparent anomalies and points of interest in general and where possible to suggest explanations.

The solvents may be classified as

(*a*) solutions of ammonium citrate, *alkaline*, *neutral* and *acid*,

(*b*) „ „ citric acid, *2 per cent.*, *1 per cent*, and *0·1 per cent.*

These two classes are not strictly comparable, and it is therefore convenient to discuss them separately.

The products investigated also differ considerably in nature but may be grouped as Steamed Bones, Raw Bones, Fish Meals, and Guanos, and they will therefore be dealt with in separate paragraphs under these heads.

STEAMED BONES.

The physical properties of all the five samples were practically identical, the difference in fineness of grinding between the 'meals' and 'flours' being scarcely perceptible.

(*a*) *The action of ammonium citrate solutions.*

The highest percentage of phosphoric acid is dissolved by the neutral, the next highest by the acid, and the lowest by the alkaline ammonium citrate solution.

It is noteworthy that the total phosphoric acid content is practically the same in each sample, and therefore, other conditions being equal,

[1] P. Wagner. *Chem. Zeit.*, 1897, **21**, 905.

the solubilities in one and the same solvent might be expected also to be nearly equal, if anything the least quantity being dissolved in the case of No. 4 (with the lowest content of P_2O_5), and the greatest in that of No. 5 (with the highest P_2O_5 content). However, the reverse holds good in every case when the solubilities are compared, so that either the phenomenon is not one of simple solution, or there must be a fundamental difference in the phosphates of the bones. In the latter

TABLE I.

No		Nitrogen %	Total P_2O_5 %	Solubility in: Alkaline Ammonium Citrate — Absolute P_2O_5 %	Alkaline Ammonium Citrate — Per cent. of Citrate soluble in Total	Neutral Ammonium Citrate — Absolute P_2O_5 %	Neutral Ammonium Citrate — Per cent. of Citrate soluble in Total	Acid Ammonium Citrate — Absolute P_2O_5 %	Acid Ammonium Citrate — Per cent of Citrate soluble in Total
1	Steamed Bone Meal	0 93	29·02	4·36	15 02	13 19	45 45	5·17	17·81
2	,, ,, ,,	1 86	29 07	2 54	8 73	9 09	31 27	8·92	30·68
3	Steamed Bone Flour.	1 12	28 60	4 64	16 22	11 90	41·60	8 00	27·97
4	,, ,, ,,	1 34	28·27	4·94	17·47	11 96	42 30	10·97	38·80
5	,, ,, ,,	1 07	29 14	4 58	15·71	12 22	·41 93	4·99	17·12

alternative we might expect to find characteristic differences in the solubilities in the different solutions. Such is indeed the case to a remarkable degree. Thus while Nos. 1, 3, 4 and 5 have similar solubilities in alkaline and neutral solutions, Nos. 1 and 5 are far less soluble in acid citrate than Nos. 3 and 4.

Again, No. 2, Steamed Bone Meal is quite exceptional in its low solubility in alkaline and neutral citrate, whereas in acid citrate its solubility is comparable with that of No. 3 or No. 4 and decidedly greater than those of Nos. 1 and 5.

(*b*) *The action of citric acid solutions.*

It is to be noted that with the 2 per cent. solution the solubilities are in order identical with the order of the percentages of the total phosphoric acid, when the trifling difference of 0·05 per cent. P_2O_5 in the total contents of Nos. 1 and 2 is overlooked. This order is not so

noticeable in the case of the 1 per cent. solution, and still less so with the 0·1 per cent. acid.

The results here, as with citrate solutions, point to the operation of some disturbing factor, such as the presence of phosphates of different solubilities in citric acid.

TABLE II.

No.		Nitrogen %	Total P_2O_5 %	Solubility in					
				0·1 % Citric Acid		1 % Citric Acid		2 % Citric Acid	
				Absolute P_2O_5 %	Per cent. of Citric soluble in Total	Absolute P_2O_5 %	Per cent. of Citric soluble in Total	Absolute P_2O_5 %	Per cent. of Citric soluble in Total
1	Steamed Bone Meal...	0·93	29·02	2·60	8·95	13·60	46·84	18·87	65·02
2	,, ,, ,, ...	1·86	29·07	2·75	9·46	12·76	43·89	18·69	64·29
3	Steamed Bone Flour.	1·12	28·60	2·89	10·10	13·73	48·00	18·33	64·09
4	,, ,, ,, ...	1·34	28·27	2·50	8·84	12·58	44·49	16·21	57·34
5	,, ,, ,, ...	1·07	29·14	2·62	9·00	16·16	55·45	20·56	70·55

The data with each separate solution are however far more uniform, the peculiar behaviour of Nos. 1, 2, and 5 towards citrate solutions not being apparent with free acid.

RAW BONES.

This category is intended to furnish examples of bone which retain their full complement of nitrogen, even though the material may have undergone some preliminary treatment. Sample No. 6 represents town-collected bones and No. 7 English raw bone, both of which still contain the natural fat. 'Degreased' bones are represented by Nos. 8 and 9, the fat being extracted on the large scale by benzene.

The three samples of bone sawings are typical pure bone meals, as also the turnings which are a by-product in the manufacture of bone buttons.

The first five were all of a similar fineness of grinding and are such as agricultural merchants sell as 'fine grist.' The sawings were much finer and comparable with steamed bone meal in this respect. The turnings were in thin flakes and exceedingly light.

(a) *The action of ammonium citrate solutions.*

TABLE III.

No.		Nitrogen %	Total P_2O_5 %	Solubility in Alkaline Ammonium Citrate: Absolute P_2O_5 %	Alkaline Ammonium Citrate: Per cent. of Citrate soluble in Total	Neutral Ammonium Citrate: Absolute P_2O_5 %	Neutral Ammonium Citrate: Per cent. of Citrate soluble in Total	Acid Ammonium Citrate: Absolute P_2O_5 %	Acid Ammonium Citrate: Per cent. of Citrate soluble in Total
6	English Bone Meal*	4 45	20 14	2·10	10·42	3·35	16·63	3 27	16·23
7	" " " *	5·01	22·00	2 28	10·36	4·19	19·04	4·44	20·19
8	" " " †	4·94	22 81	2·41	10·56	3 94	17 27	3·43	15·03
9	" " " †	5 17	22 46	2·46	10·95	4·21	18 74	5·45	24·26
10	Indian Bone Meal‡	3·35	23 19	1·47	6·33	3 89	16·77	3·44	14·83
11	Bone Sawings‡	4·03	25 51	3·25	12 74	9·66	37·87	6·76	26·49
12	" " ‡	4·02	24·92	2·57	10·31	10·59	42·49	5·40	21·67
13	" " ‡	3 96	25 02	3·58	14 31	9·51	38·01	6·65	26·57
14	Bone Turnings‡	4·07	25·79	4·07	15·77	11·62	45·05	9·15	35·47
15	" " ‡	3·97	25·64	4·58	17·86	12·25	47·77	12 19	47·54

* 'Undegreased.' † 'Degreased.' ‡ Well-cleaned.

In general the solubility is greatest in the case of neutral ammonium citrate. There are two exceptions, viz. No. 7 and No. 9, which both give the highest figure with the acid solution. It may be noted that these two samples, Nos. 7 and 9, are the richest in nitrogen, which may have something to do with their relatively low solubility in neutral citrate, although no connexion between the amount of nitrogenous matter and of soluble phosphoric acid is apparent in the case of the other samples.

As in the case of steamed bones, considerable differences are shown here between products of similar physical characteristics and chemical composition. The results obtained from the bone-sawings are worthy of attention in this connexion. In appearance and fineness they are exactly alike, and although the total phosphoric acid is practically equal in each, yet No. 12 is decidedly less soluble in alkaline and in acid citrate, but more soluble in neutral solvent than the other two (Nos. 11 and 13).

On comparing the two samples of 'degreased' bones it will be noticed that the solubilities do not agree well. Although No. 9 contains less total phosphoric acid than No. 8 yet it has rather higher citrate solubilities, notably in acid solution.

The data for the 'undegreased' meals offer no particular interest.

(b) *The action of citric acid solutions.*

TABLE IV.

No.		Nitrogen %	Total P_2O_5 %	Solubility in 0·1 % Citric Acid: Absolute P_2O_5 %	0·1 % Citric Acid: Per cent. of Citric soluble in Total	1 % Citric Acid: Absolute P_2O_5 %	1 % Citric Acid: Per cent. of Citric soluble in Total	2 % Citric Acid: Absolute P_2O_5 %	2 % Citric Acid: Per cent. of Citric soluble in Total
6	English Bone Meal*	4·45	20·14	1·19	5·90	5·60	27·80	9·51	47·23
7	" " " *	5·01	22·00	2·09	9·50	7·55	34·31	11·50	52·27
8	" " " †	4·94	22·81	1·93	8·46	7·65	33·53	11·36	49·80
9	" " " †	5·17	22·46	1·58	7·03	8·60	38·29	12·73	56·67
10	Indian Bone Meal‡	3·35	23·19	1·32	5·69	7·02	30·27	12·22	52·29
11	Bone Sawings‡	4·03	25·51	2·65	10·39	11·94	46·80	18·32	71·81
12	" " ‡	4·02	24·92	2·62	10·51	12·33	49·48	20·16	80·89
13	" " ‡	3·96	25·02	2·68	10·71	12·38	49·48	20·27	81·01
14	Bone Turnings‡	4·07	25·79	2·57	9·96	16·45	63·75	24·41	94·64
15	" " ‡	3·97	25·64	2·49	9·71	15·99	62·36	21·40	83·46

* 'Undegreased.' † 'Degreased.' ‡ Well cleaned.

With the 'undegreased' meals and bone turnings it is seen that the order of solubility in 2 per cent. acid corresponds to the order of the total P_2O_5 in the samples. This does not hold however for the 'degreased' bones, nor for the sawings—No. 11 being notably exceptional. The regularity is still less apparent in the results obtained with the weaker acid solutions.

The exceedingly high solubility of bone 'turnings' No. 14 in the 2 per cent. solution is worthy of note; also the same sample with all three free acid solutions gives higher solubilities than its fellow No. 15, whilst with citrate solutions (Table III.) the order is reversed in the case of each solvent, the difference being most pronounced in acid citrate.

Attention should also be called to the decidedly higher solubilities in 2 per cent. acid of the 'sawings' than of the steamed products (see Table II), which are certainly not more coarse grained than the former.

Fish Meals.

The samples under investigation are representative of several processes of manufacture, yet in general physical properties are closely allied. In the matter of fineness of division No. 19 was the coarsest and No 20 the finest material, the remaining three samples being intermediate. As the question of the amount of oil sometimes arises in the consideration of fish meal as a manure, the percentages of this constituent are added to the table. The meals containing a low percentage of oil are manufactured largely from the heads, etc. of 'white' fish, notably cod. A preponderance of herring refuse produces an article inconveniently rich in oil, No. 20 is a typical example of such material.

(a) *The action of ammonium citrate solutions.*

TABLE V

No.		Nitrogen %	Total P_2O_5 %	Solubility in: Alkaline Ammonium Citrate		Neutral Ammonium Citrate		Acid Ammonium Citrate		Oil %
				Absolute P_2O_5 %	Per cent. of Citrate soluble in Total	Absolute P_2O_5 %	Per cent. of Citrate soluble in Total	Absolute P_2O_5 %	Per cent of Citrate soluble in Total	
16	Fish Meal	8·97	8 87	1·99	22 43	4 91	55 35	3·62	40·81	4·96
17	,, ,,	8 68	10 14	2 51	24·75	6 95	68 54	3·85	37·96	8·48
18	,, ,,	8·27	8·88	2·43	27·36	5·69	64·07	4·48	50·45	8·11
19	,, ,,	8·30	7 36	1·48	20·11	3·49	47·41	2·94	39·94	8·83
20	,, ,,	8 78	6·59	1 71	25 95	3·59	54 47	3·14	47·64	16·46

The order of the solvent power of the solutions remains the same, viz., neutral the greatest, followed by acid, and alkaline citrate in turn; this statement is valid in each case in point.

There is no apparent connexion between the order of the citrate solubility and the order of the percentage of total P_2O_5 or of nitrogen, as was noted in some instances with bones. However, it is noteworthy that

whilst Nos. 16 and 18 have practically the same content of total phosphoric acid, No. 16 the richer in nitrogen (8·97 per cent.) yields lower solubilities than No. 18 (nitrogen = 8·27 per cent) in every case. It will be remembered that the raw bones No. 7 and No. 9 in Table III gave exceptionally low solubilities with neutral solution, at the same time being richest in nitrogenous matter.

It is commonly said that a high percentage of oil in fish meal prevents rapid action of the manure in the soil[1]. This is in nowise borne out by the present results as far as the solubility of the phosphates is concerned; indeed if No. 16 and No. 18 are once more compared, No. 18 containing by far the larger percentage of oil, yields the greater proportion of its phosphates to all three citrate solutions. Again, No. 20 with more than 16 per cent. oil gives solubilities quite comparable with those of the remaining samples.

(*b*) *The action of citric acid solutions.*

TABLE VI.

No.		Nitrogen %	Total P_2O_5 %	Solubility in 0·1 % Citric Acid: Absolute P_2O_5 %	0·1 % Citric Acid: Per cent. of Citric soluble in Total	1 % Citric Acid: Absolute P_2O_5 %	1 % Citric Acid: Per cent. of Citric soluble in Total	2 % Citric Acid: Absolute P_2O_5 %	2 % Citric Acid: Per cent. of Citric soluble in Total	Oil %
16	Fish Meal	8·97	8·87	2·14	24·13	5·48	61·78	7·17	80 83	4·96
17	,, ,,	8·68	10·14	2·61	25·74	6·05	59·66	8·43	83·13	8·48
18	,, ,,	8·27	8·88	2·06	23·20	5·58	62·83	6 96	78·38	8·11
19	,, ,,	8·30	7 36	1 50	20·38	4·19	56·92	5·35	72·69	—
20	,, ,,	8·78	6·59	1·79	27·16	4·20	63 73	4·26	64·64	16·46

With 2 per cent. solution there is a tendency for the order of the solubilities to arrange themselves in the order of the total phosphoric acid percentages. This was the case with steamed bones (Table II), also with 'undegreased' bones (Table IV). There is no sign of such regularity in the case of the weaker solutions.

[1] "Indeed, some experiments seem to show that an excessive percentage of oil retards decomposition, not only in the fish meal itself, but in the adjacent particles of soil."—*Artificial Fertilizers* (H. Richardson & Co.), 1895.

As regards the influence of the presence of oil, if No. 16 and No. 18 are again compared, it is seen that with 2 per cent. and 0·1 per cent. solutions No. 18 (8·11 per cent. oil) gives the lower solubilities, whilst in the case of the 1 per cent. solution No. 16 (4·96 per cent.) is the less soluble, though in every case there is no great difference. It will also be noticed that the difference of the solubilities in 2 per cent. and 1 per cent. solutions of No. 20 is very small.

GUANO.

A study of the analyses of a few cargoes of guano of different origin would at once reveal what a variable material is being dealt with.

Two varieties of guano are now imported:—

(1) Nitrogenous and phosphatic, containing from 7 per cent. to 11 per cent. nitrogen, and 5 per cent. to 15 per cent. phosphoric acid, and generally termed 'ammoniacal.'

(2) Phosphatic, containing upwards of 15 per cent. phosphoric acid with generally less than 3 5 per cent. of nitrogen.

It is almost impossible to say how the various acids and bases in this substance are distributed, as the chemical nature is so highly complex[1].

The samples of phosphatic guano represent two classes, (1) 'older' and (2) 'newer' guano. The former variety has remained for a long period before being worked, and in consequence has lost nitrogen and become more highly phosphatic; this class is represented by samples Nos. 21, 22, and 23. The 'newer' guano is typified by samples Nos. 24 and 25 and their bulks are not of such ancient origin.

(*a*) *The action of ammonium citrate solutions*

Generally the phosphates of the samples richest in nitrogen are the more easily attacked in the case of each solvent. The notable exception is No. 27; in the alkaline solution it yields only 19·11 per cent. of its phosphoric acid, an amount comparable with that yielded by the phosphatic sample No. 25 (19·05 per cent.), and less than the solubility of No. 24 (23·41 per cent.).

[1] For detailed analyses of Peruvian guano see Wagner's *Chemical Technology*, 1892, p. 424; or *Manual of Agricultural Chemistry*, Herbert Ingle, 1902, pp. 180–181.

In the case of the phosphatic selection the order of the solubilities in neutral solvent is the exact opposite of the order of the figures for total P_2O_5, and with the acid citrate the absolute percentages show the same characteristic, while with alkaline solution there is no such correspondence.

TABLE VII.

No.	Guano	Nitrogen %	Total P_2O_5 %	Solubility in: Alkaline Ammonium Citrate: Absolute P_2O_5 %	Alkaline Ammonium Citrate: Per cent. of Citrate soluble in Total	Neutral Ammonium Citrate: Absolute P_2O_5 %	Neutral Ammonium Citrate: Per cent. of Citrate soluble in Total	Acid Ammonium Citrate: Absolute P_2O_5 %	Acid Ammonium Citrate: Per cent. of Citrate soluble in Total
21	Peruvian 'Phosphatic'	2·11	30·45	2 33	7·65	6·95	22·82	5·28	17·34
22	,, ,,	1·64	26·13	2·97	11 36	8 38	32·07	6 84	26·17
23	,, ,,	1·40	27·28	2·23	8·17	8·28	30 31	6·26	22·94
24	,, ,,	2·83	22 64	5·30	23·41	11·20	49·47	10 14	44 78
25	,, ,,	3·26	21·36	4·07	19·05	12 57	58·84	12 18	57·02
26	,, Ammoniacal	8·11	13·13	5·86	44 63	11·05	84·15	9·56	72 81
27	,, ,,	6·19	13·29	2 54	19·11	11 62	87·43	8·64	64·55
28	Damaraland ,,	6 83	14·63	4·51	30·82	9·76	66 71	8·24	56 32

The order of the solvent power of the solutions is without exception the same as before, viz., (1) neutral, (2) acid, (3) alkaline ammonium citrate.

(b) *The action of citric acid solutions.*

As in the case of the citrate solutions, the nitrogenous manures are the more soluble. The order of the solubilities in 2 per cent. solution resembles to some extent the order yielded by the neutral citrate solvent in that the solubilities become less as the total phosphoric acid increases. Here the nitrogenous guanos participate in this regularity, which it will be noticed ceases in the case of the samples richest in phosphates. The same phenomenon is apparent in the results obtained from using the 1 per cent. solution, the only exception being No. 26. With the 0·1 per cent. acid no such regularity is noticeable.

In discussing the solubilities of steamed and other bones in free acid solutions, it was remarked that the solubilities in the stronger acid solvents increased or tended to increase with the total P_2O_5; in the case of the guanos, as noticed above, the tendency is in the opposite direction.

TABLE VIII.

No.	Guano	Nitrogen %	Total P_2O_5 %	Solubility in					
				0 1 % Citric Acid		1 % Citric Acid		2 % Citric Acid	
				Absolute P_2O_5 %	Per cent. of Citric soluble in Total	Absolute P_2O_5 %	Per cent. of Citric soluble in Total	Absolute P_2O_5 %	Per cent. of Citric soluble in Total
21	Peruvian 'Phosphatic'	2 11	30·45	3·81	12·51	15·17	49·81	21·47	70·50
22	,, ,,	1·64	26·13	4 10	15·69	13·73	52 54	18·17	69·58
23	,, ,,	1·40	27·28	4·01	14 69	13·66	50·07	18·02	66 05
24	,, ,,	2 83	22·64	5·25	23 18	16 54	73·05	19·25	85·02
25	,, ,,	3 26	21 36	5 11	24·39	14·91	69·80	18·36	85·95
26	,, Ammoniacal	8·11	13 13	6·14	46·76	10·60	80·73	12·57	95·73
27	,, ,,	6 19	13 29	5·41	40 70	11·95	89·91	12·66	95·26
28	Damaraland	6·83	14·63	6 36	43·47	12·01	82·09	13·10	89·54

It is also worthy of note that, with the single exception of No. 21, the solubilities of the remaining samples in 0 1 per cent. citric acid are in the identical order of their nitrogen contents.

SUMMARY.

With such conflicting results it is difficult to draw definite conclusions. The data are not put forward with that object, but it was felt that there is sufficient interest in the figures themselves to warrant publication. This communication is intended as an interim report on investigations which will be continued as time and occasion permit. However, the general features most worthy of note are as follows:—

(1) The order of the solvent power of the three solutions of each of the two classes remains the same throughout. In the citrate solutions the order is (descending), (1) neutral, (2) acid, (3) alkaline solution, with only two exceptions, viz., the raw bone meals No. 7 and No. 9, discussed under Table III.

With the free acid the solubilities are in the order of the strength of solution without exception.

(2) The presence of free ammonia in the citrate solution lowers the solubility and the amount of lowering varies with different products. To emphasise this a few of the manures were treated with a solution containing 10 per cent. citric acid made strongly ammoniacal and allowed to stand 18 hours at the ordinary temperature. The proportions of phosphoric acid dissolved are set forth in Table IX.

TABLE IX.

No.		Total P_2O_5 %	Soluble P_2O_5 Absolute %	Per cent. of Citrate soluble on Total
4	Steamed Bone Flour	28·27	2·21	7·82
6	Bone Meal (raw)	20·14	0·42	2·08
10	Indian Bone Meal	23 19	0·69	2·98
15	Bone Turnings	25·64	1·18	4·60
18	Fish Meal	8·88	1·14	12·83

(3) Bones of similar chemical composition and physical properties, and containing practically the same percentage of total phosphoric acid, have different solubilities in the same citrate or citric acid solution, *e.g.* the steamed bone meals Nos. 1 and 2 (Tables I and II), the bone-sawings Nos. 11, 12, and 13 (Tables III and IV). Moreover, as referred to in discussing steamed bone under Table I, this observation leads one to infer (1) that the action of the solvent is either not one of simple solution, or (2) that there is a fundamental difference in the phosphates of the bones.

In support of the latter alternative is the fact that the samples comparable in chemical and physical properties and with equal percentages of total phosphoric acid show vastly different solubilities in different solutions.

Also this second view is in accord with that of Gebek, who, as mentioned before, in studying the solubility of bone phosphates in citric acid solution concluded that only a small portion of the phosphoric acid of bone exists as tricalcium phosphate, and suggested that the remainder is in the form of dicalcium phosphate and a tribasic phosphate of some organic base. It should be noted that Gebek's method of obtaining his results was by altering the character of the bone previous to treatment with citric acid, a method unlike that by which the results have been arrived at in the present work. It is hoped that subsequent investigations will elucidate this point.

The writer is grateful to his friend Charles Crowther, M.A., Ph.D., of the Department of Agriculture, Leeds University, for help and valuable suggestions.

ON THE QUESTION WHETHER NITRITES OR NITRATES ARE PRODUCED BY NON-BACTERIAL PROCESSES IN THE SOIL.

By EDWARD J. RUSSELL, D.Sc. (Lond.), *South-Eastern Agricultural College, Wye*, AND NORMAN SMITH, M.Sc. (Vict.), *Victoria University, Manchester.*

The experiments described in the following pages were made with a view to discover how far purely physical and chemical processes, known to take place in the soil, may be expected to give rise to nitrites and nitrates. Scattered throughout the extensive literature on nitrification are occasional papers tending to show, what might also be expected on theoretical grounds, that non-bacterial processes may be important sources of nitrates. Formerly these processes were considered to be the only sources, then came the brilliant researches of Schloesing and Muntz, Warington, Winogradsky, and others on nitrifying organisms, and non-bacterial processes were forced into the background. Now that a full knowledge of the various sources of nitrogen compounds in the soil has become so indispensable to the agriculturist, it seemed desirable to make a careful examination of the various chemical and physical processes known to take place in the soil, and to ascertain whether they make any direct or indirect contribution to its stores of nitrates. To this end we have repeated and extended such of the recorded observations bearing on the subject as seemed to merit repetition; we have also devised other experiments to make the examination as complete as possible.

We have confined ourselves entirely to the possible "fixation" of atmospheric nitrogen and ammonia. The other question, the decomposition of that portion of the nitrogenous matter in the soil supposed to resist the action of bacteria, we have for the present left alone. We have also attempted no measurements of the amount of ammonia the soil takes from the air apart from that actually washed in by the rain.

Our experiments fall into three groups, and deal with the possibility of forming nitrites and nitrates during,

(A) the evaporation of water;

(B) the oxidation of free nitrogen by (1) catalytic processes, (2) induced oxidation[1];

(C) the oxidation of ammonia.

A. THE ALLEGED FORMATION OF AMMONIUM NITRITE DURING THE EVAPORATION OF WATER.

Few, if any of the remarkable observations made by Schönbein have caused more discussion than one published in 1862[2], to the effect that the evaporation of water in air produced ammonium nitrite. It was immaterial whether evaporation took place from metal or earthenware dishes, from wet cloth, paper, or sand; in all cases, Schönbein maintained, nitrogen combined with some of the evaporated water and ammonium nitrite was synthesised. The observation attracted immediate attention, for at that period synthetical processes figured prominently among the chemical questions of the day: Kolbe, Frankland and others were synthesising organic compounds, and Berthelot had only two years previously published his *Chimie organique fondée sur la Synthèse.*

Owing to various causes, among others the absence of delicate characteristic tests for nitrous acid[3], Schönbein's experiments were difficult to carry out, and during the succeeding 20 years discussion was continued, some chemists failing to obtain Schönbein's results, others confirming and extending them[4].

Without going into the details of this discussion it may be noted that interest largely centred round the question whether ammonium nitrite was formed during the distillation of water, or during its rapid evaporation; the slower evaporation taking place at ordinary tempera-

[1] We use the expression "induced oxidation" in preference to "autoxidation" to denote the acceleration of the rate of oxidation of one substance brought about by the simultaneous oxidation of another.

[2] *Annalen Chem. u. Pharm.* 1862, 124, 1.

[3] The Griess-Ilosvay test for nitrous acid was introduced in 1879.

[4] Among the former were Böhlig (*Ann. Chem. Pharm.* 1863, 125, 21); Carius (*ibid.* 1874, 174, 31); Weith and Weber (*Berichte* 1874, 7, 1745); Warington (*Journ. Chem. Soc.* 1881, 39, 229), and Baumann (*Landw. Versuchs. Stat.* 1888, 217); Neumann, *Chem. Centr.* 1890, 665); on the other hand, Zabelin (*Ann. Chem. Pharm.* 1864, 130, 82), v. Loesicke, *Arch. Pharm.* 1879 [3] 14, 58; Scheurer-Kestner (*Bull. Soc. Chem.* 1883; [2] 39, 289); and Schaer (*Arch. Pharm.* 1905, 243, 198) supported Schönbein's contention.

tures was not so fully investigated. It is this slow evaporation, however, which takes place from the soil, and is therefore of chief interest to the agricultural chemist.

In the first series of experiments we repeated the work of previous investigators.

Series I. 1. A fine stream of carefully purified air was drawn through water at various temperatures ranging from 15–18° C. for periods of 14 to 120 hours.

2. Water was allowed to evaporate from a strip of filter-paper hung in pure air.

3. Water was allowed to evaporate from platinum and porcelain dishes kept in well-fitting desiccators. In another series of experiments the drying agent in the desiccator (sulphuric acid) was replaced by water so that evaporation was always counterbalanced by condensation.

4. In the above experiment the surface was increased, and the conditions made to approximate to those obtaining in the soil, by addition of a quantity of ferric oxide.

As a test for nitrous acid we used the Griess-Ilosvay reagent[1], which readily detects 1 part in one hundred million of water. In none of the above experiments, however, did it give the slightest sign of the presence of a nitrite. With so delicate an indicator the experiments are naturally difficult to carry out, the dust, and even the air of a laboratory, contain nitrites, and some samples of glass contain sufficient to give quite an appreciable reaction.

From the description of their experiments given by Zabelin, v. Loesicke, and Scheurer-Kestner, it is quite evident that they failed to exclude these sources of contamination.

Series II. In 1902 Elster and Geitel[2] discovered that soils contain radio-active substances, and their results have been found to hold good both here and in America.

The next series of experiments were designed to discover whether these radiations had any effect in producing ammonium nitrite.

[1] The reagent consists of two solutions, (*a*) 1 grm. of sulphanilic acid ($C_6H_4NH_2SO_3H$) is dissolved in 14·7 grams of glacial acetic acid and 285 c.c. water. This is best done by warming the sulphanilic acid with the acetic acid, to which an equal bulk of water has been added. The remaining water must be added carefully. (*b*) 0·2 gram of a naphthylamine is dissolved in 14·7 grams of glacial acetic acid and 325 c.c. water, taking the same precautions as before. The two solutions are kept separate. 1 c.c. of each is added to the liquid under examination.

[2] *Physikalische Zeitschrift*, 1902, 3, 574: see also Ebert and Ewers, *ibid.* 4, 162.

1. A tube of radium bromide was fixed just above the surface of water evaporating into purified air from a platinum dish contained in a large desiccator. The emanations were of course many times more powerful than those in the soil.

2. An insulated platinum dish containing water was connected with the negative pole of a large Wimshurst machine and maintained at a high potential for some hours. The experiment was conducted out-of-doors in order that the electro-positive ions of the air might travel to the water.

In neither case was any ammonium nitrite found.

Series III. The influence of an electrical field and of sunlight was examined.

1. A platinum dish containing water was connected with one pole of a battery; and a platinum disc, of about the same diameter as the dish, and fixed three inches above it, was attached to the other. A potential difference of 160 volts was maintained for 14 days.

2. Experiments 3 and 4 of Series I. were carried out in bright sunlight during the summers of 1903–4–5.

Again we were unable to detect any trace of ammonium nitrite.

So far as we know, the above include all the conditions obtaining in the soil, and in every case negative results have been obtained. We are therefore justified in concluding that the evaporation even of large quantities of water from the soil does not lead to the formation of any ammonium nitrite.

B. A POSSIBLE OXIDATION OF NITROGEN IN THE SOIL.

This might arise in two ways, by catalytic action or by induced oxidation.

Series IV. Catalytic action. Oxygen and nitrogen readily unite at high temperatures, and the tendency no doubt exists at ordinary temperatures, but is in some way kept in check. In analogous cases reaction can be brought about by catalytic agents, and we have tried their effect here also, selecting platinum, ferric oxide, and soil as the catalysts.

1. Platinum as catalyst. Loew[1] left platinum black mixed with caustic baryta exposed to air for two days, and found distinct quantities of nitrite produced. Owing to the difficulty of carrying out the experiment under perfectly satisfactory conditions we are not in a position to

[1] *Ber.* 1890, 23, 1443.

confirm or deny this statement. Ignited platinum certainly has no such power.

2. Ferric oxide as catalyst. Bonnema[1] claims that ferric oxide can bring about combination, Fausto Sestini[2] on the other hand, that it does not. Our experiments were an extension of those in Series I, 4, and gave entirely negative results, neither ammonium nitrite, nor nitrate being detected[3].

3. Humus as catalyst. Simon[4] states that humus can absorb nitrogen from the air, converting it into ammonia. Prevost[5] showed this was not the case. We also found that in absence of bacteria humus has no power of fixing nitrogen.

4 Soil as catalyst. We have in various ways tried to ascertain whether the soil as a whole has the power of inducing the combination of nitrogen and oxygen, but have failed to discover the slightest indication of any such power. The result of course was more or less to be expected, as it is hardly likely that soil should possess greater catalytic power than ferric oxide.

Series V. Induced oxidation. Many cases are known where the oxidation of one body facilitates the oxidation of another, and in view of the extent to which oxygen is absorbed by the soil it seemed quite possible that this process might facilitate the union of atmospheric nitrogen and oxygen.

(*a*) *Experiments with soils.* There is considerable difficulty in experimentally testing this hypothesis because oxidation in soil is mainly, though not entirely, bacterial; if the conditions are rigidly aseptic so little oxidation takes place that induced oxidation cannot be a factor of importance: whilst if bacteria capable of oxidising organic matter are present any nitrate formed may always be due to their activity rather than to other processes.

It is not, apparently, a difficult matter to kill nitrifying organisms. They cannot withstand an insufficient supply of moisture, and by drying the soil in a steam-oven for some time they are all destroyed.

[1] *Chem. Zeit.* 1903, 27, 149.

[2] *Landw. Versuchs. Stat.* 1904, 60, 103.

[3] For nitrates we used the phenol sulphonic acid test as modified by Wiley, and found it worked admirably. Mix 15 grams of phenol with 92·5 c.c. of sulphuric acid and 7·5 c.c. of water and digest on the water-bath. The solution to be examined is evaporated to dryness on the water-bath, 1 c.c. of the reagent is added, then 1 c.c. of water, the whole warmed and allowed to stand for 15 minutes. It is then diluted to 25 c.c. and made alkaline with ammonia, when a yellow colour appears.

[4] *Landw. Versuchs. Stat.* 18, 452.

[5] *Trans. Chem. Soc.* 1881, 371.

1. 20 grams of soil placed on a large watch-glass were dried at 100° in the steam-oven. The soil was then moistened with 5 c.c. of sterilised distilled water, supported over a large dish of dilute sulphuric acid, and covered with a large bell-jar also standing in the dish. The acid thus forms a lute; air entering as the result of changing temperature or pressure has first to pass through the acid where any ammonia would be retained.

2. Another 20 grams were dried at the same time in a weighing bottle and kept dry.

After 20 days the nitrite and nitrate were estimated in both soils. We found it more convenient in dealing with soils to discontinue the colour tests, and to determine the nitrite and nitrate by the usual reduction method after previously removing all the ammonia present.

Soil	Nitric N, before experiment	Nitric N, after experiment	Difference, parts per million of dry soil
Old chalk pasture, dried 15 hours .	7·5	37·5	30
Rich garden soil, dried 2 hours . ..	8	10	2
Alluvial pasture soil, dried 2 hours.	5	9	4

Apparently all possibility of bacterial action is out of the question and the increase in nitrates must be due to purely chemical causes. The conditions, however, are not really aseptic. Tested in the apparatus described in a previous paper[1], the soils showed after prolonged drying at 97°, and subsequent moistening with sterilised distilled water, a considerable capacity for taking up oxygen. As all the micro-organisms do not seem to have been killed, the results may be explained in three ways:

(1) nitrifying organisms may have been present;

(2) there may have been some organisms, differing from the ordinary nitrifying organism, producing nitrate from the nitrogenous substances present;

(3) induced oxidation may have taken place.

(1) seems unlikely; (2) is not improbable, in fact Fraps[2] has obtained evidence of the existence of organisms capable of producing nitrates direct from organic matter; (3) is also probable. There seems to be no way of directly deciding between the second and third hypotheses, but

[1] This *Journal*, Part 3, p. 261.

[2] *Amer. Chem. Journ.* 1903, 29, 236.

the indirect evidence adduced later on is very clearly against induced oxidation.

When antiseptics were added to the soil no increase in the nitrates could be detected, even after three weeks' exposure to pure air.

Soil	Nitric N, before experiment	Nitric N, after experiment	Difference, parts per million of dry soil
Wye hop garden + ·04 % $HgCl_2$	50	49	−1
Old pasture (Gault) + chloroform .	25	25	*nil*

(*b*) *Experiments with pure substances.* This is by far the most satisfactory method of testing the induced oxidation hypothesis, since complications arising from bacterial action are entirely avoided.

For the earliest recorded observations on the production of ammonium nitrite and nitrate during oxidations we have again to go back to Schönbein, who stated that these bodies arise when phosphorus oxidises in moist air. Subsequent workers have confirmed this statement[1]. It has also been said that ammonia is produced during the rusting of iron, and that traces of nitric acid are formed in the slow oxidation of ether[2].

We have made a number of experiments with pure substances, but, as they are only of indirect interest for our present purpose, and as an account of them is appearing elsewhere, it is only necessary to very briefly state the results. The method of experiment was essentially the same as for the soils, but we reverted to colour tests, owing to their greater sensitiveness. The substances investigated were of the most varied description, and comprised phosphorus, sodium, potassium, magnesium, calcium, zinc, tin, iron, manganous hydrate, ferrous hydrate, cuprous oxide, and cuprous chloride. In many experiments we found traces of ammonium nitrite, or nitrate, but in no instance did the total amount of nitrogen thus combined exceed ·005 milligram for about 5 grams of substance oxidised. Even if the whole of this nitrogen had come from the atmosphere and been oxidised by induced oxidation processes we should only have about 1 part of nitrogen "fixed" for every million parts of oxygen absorbed. A quantity of this order of magnitude

[1] Cf. Berthelot, *Ann. de Chimie*, 1877 [5] 12, 440.

[2] Cf. Berthelot, *Comptes Rendus*, 1889, 108, 543. The idea that ammonia is produced when moist iron and zinc are allowed to stand in air was commonly held at one time, see Gmelin's *Handbook*, Vol. 2, p. 417.

is manifestly negligible, and we may dismiss the hypothesis that induced oxidation of nitrogen takes place in the soil.

C. OXIDATION OF AMMONIA IN THE SOIL.

The percentage of ammonia in the air is exceedingly minute, but the absolute quantity coming in contact with an acre of soil during the year must be fairly considerable. It is not yet known how much of this is actually absorbed, determinations made by exposing sulphuric acid to the air[1] have indicated about 40 lbs. per acre per annum, but these results are not entirely applicable to soil-absorption.

Apart from bacterial action, oxidation may proceed in two ways, by catalytic action and by induced oxidation, and each has been made the subject of experiment.

Series VI. Catalytic action. The extensive literature dealing with this subject need not be referred to here. As an example of the investigations carried out in this direction we may mention one paper by Fausto Sestini[2], who showed that moist ferric oxide will at ordinary temperature bring about the oxidation of ammonia, and he concludes that this reaction takes place in the soil.

Soil	Nitrate present after 2 weeks' exposure to		Difference, parts per million of dry soil
	pure air	air mixed with NH_3	
Light sand (Lower Greensand)	10	10	0
Chalky loam + ·05 °/₀ phenol	57·5	57·5	0

1. About 10 grams of ferric hydrate, washed free from all traces of nitrous and nitric acids, were exposed in the apparatus already described (p. 449) to an atmosphere containing ammonia for 10 days[3]. When the ferric oxide stood in a glass vessel distinct quantities of nitrite and nitrate were obtained, but when we used a platinum vessel much less was produced. If ammonia solution is allowed to stand in contact with glass it will usually dissolve out in quite a short time sufficient nitrite

[1] Collard de Martigny (*Journ. de Chimie Médicale*, 1827, III. 517) was one of the first to make the experiment in this way.

[2] *Landw. Versuchs. Stat.* 1904, 60, 103.

[3] This was secured by placing in the apparatus a small dish of concentrated ammonia solution, which was renewed from time to time.

to give a distinct reaction with the Griess-Ilosvay solution; and we think the high results obtained by Sestini are in part due to the fact that he used glass.

2. The experiment was repeated with manganese dioxide, lead dioxide, and stannic oxide, and in each case a slight oxidation of ammonia took place, amounting, however, only to ·01 – ·1 milligram in 3 or 4 weeks.

3. 20 grammes of a sandy soil (Lower Greensand) known not to undergo much oxidation was next exposed to the ammoniated atmosphere. In other experiments a rich loam, sterilised with ·05 °/₀ phenol, was used.

Evidently no oxidation of ammonia has taken place.

Series VII. Induced oxidation of ammonia. It has long been known that ammonia not only favours the oxidation of metals with which it is in contact, but is itself oxidised during the process; this is notably the case with copper, and, to a less extent, with zinc, and tin, with manganese and ferrous hydroxides, and with phosphorus. In fact ammonia oxidises far more readily in this way than by a catalytic action. Some difficulty arises in dealing with soils; nitrifying organisms must be removed and yet oxidation must be allowed to take place.

Soil	Nitrate present after 3 weeks' exposure to		Difference, parts per million of dry soil
	pure air	air mixed with NH_3	
Old Chalk pasture soil (dried 15 hrs. at 95°)	37·5	40	+2·5
Alluvial pasture soil (dried 2 hours, at 95°)	9	7	–2
Old pasture (Gault) treated with chloroform	25	44	+19
Hop garden, Wye	62·5	75	+12·5

In no case is bacterial action excluded: presumably nitrifying organisms would be destroyed by heat or by chloroform, and even if they were not, an atmosphere saturated with ammonia would probably be unfavourable to their activity.

We found by direct experiment that the soils still vigorously absorbed oxygen after being heated or treated with chloroform, the conditions were therefore favourable for induced oxidation. In the alluvial pasture soil it did not take place, in the Gault it apparently did.

There is some uncertainty about the Chalk pasture and about the hop garden soils, the latter was not treated in any way and contained nitrifying organisms.

It seems quite probable that some nitrate may be formed from ammonia in the soil by this process.

CONCLUSIONS.

Taking the results as a whole we find they are conclusively against any measurable formation of nitrites or nitrates in the soil from atmospheric nitrogen or ammonia by chemical or physical processes.

The first series of experiments shows that in no circumstances does the evaporation of water produce ammonium nitrite.

Oxidation of free nitrogen might theoretically be expected to take place in the soil either by catalytic or by induced oxidation processes. There is considerable difficulty in testing the latter hypothesis owing to bacterial complications, but the indirect evidence adduced from experiments with pure substances shows that if induced oxidation takes place at all its effects are so extremely slight that in practice they would be altogether negligible.

Catalytic oxidation of nitrogen does not seem to occur in the soil.

Slightly different results were obtained with ammonia. As the higher oxides of iron and manganese possess a slight power of catalytically oxidising ammonia, it might be expected that soils in which they occur to any extent would possess the same power; in any case, however, the effect is only small, and appears to be of no practical consequence.

On the other hand, ammonia oxidises more readily in presence of other substances undergoing oxidation. Experiments with soils showed that this induced oxidation may, under certain rather artificial circumstances, come into play as a factor in producing nitrates; but it must be remembered that at the low partial pressures of ammonia obtaining in nature, bacterial nitrification would be more prominent than in our experiments. Taking this point into consideration, the induced oxidation of ammonia cannot be regarded as an important source of nitrates under natural conditions.

SOME PRELIMINARY NOTES ON THE PHYSICAL PROPERTIES OF THE SOILS OF THE GANGES VALLEY, MORE ESPECIALLY IN THEIR RELATION TO SOIL MOISTURE.

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INTRODUCTION

IN a stretch of arable lands like those of the Ganges Valley, although damage may be caused by occasional floods, which are sudden and of short duration, the more general, and by far the most serious loss is due to deficiency of moisture of the soil: thus the relation of the soil to soil moisture becomes of more than ordinary importance Dr Voelcker[1], in his Report on Indian Agriculture, remarks "In India the relation of soils to moisture acquires a greater significance than almost anywhere else.... .." This relation is fundamental, for on it depends the methods for the conservation of soil moisture, for the economical application of irrigation water, and for the treatment of barren and salt lands—all problems of direct interest to agriculturists in the plains of Northern India. The methods for dealing with these problems must be largely—if not entirely—empirical until such time as the behaviour of the soil in its relation to moisture is investigated The problem in all its various branches is enormous, and in a country in which the seasons follow each other with such rapidity, and vary the one from the other in so marked a manner, it frequently happens that a particular point, if not determined within a period of a few days, must await solution until the following year. It is impossible, therefore, that a series of observations covering a period of barely twelve months should be other than of a purely preliminary nature, and it is in full recognition of this fact that they are here given. Further work will be necessary before it can be

[1] "Report on the Improvement of Indian Agriculture," 1893, p. 42.

considered proved that what is here put forward as a possible explanation of the observed facts is in reality the true explanation. For the present it can merely be stated that the experimental evidence points to the probability of the relation to be indicated.

Although the climate and usual methods of cultivation are matters of common knowledge, it will, for several reasons, be convenient to give a brief survey of the main features of the districts under consideration. These accounts are in no sense exhaustive, and in some cases even, some of the main features are omitted. They will serve, however, to emphasise those points to which the present experiments have reference.

The chief line of enquiry has been that of the relation of soil to soil moisture. Certain preliminary determinations are, however, necessary for the interpretation of results, and since the soil differs so materially from the common types of England, the Continent, and America, on which the major portion of the work on soils has been done, it seemed preferable to re-determine these for the actual soils under consideration[1]. These determinations are here given. One, however, and possibly the most important, namely, mechanical analysis, has to be omitted until such time as opportunity offers for making the necessary determinations. It may be noted in this connexion that in alluvial soils like those under consideration, with little organic matter, and in which the ultimate particles are so minute, mechanical analyses will in all probability prove of more than ordinary importance.

Weather. The main features of the weather are best considered under the three separate headings of (1) Rainfall, (2) Temperature, and (3) Humidity.

Rainfall. In addition to indicating the essential characteristics of the normal season, the following table notes the peculiarities of the particular season under consideration:—

[1] For similar reasons the references to the somewhat bulky literature which has been consulted have been omitted.

(1) *Rainfall.*

	Average[1]		Actual figures for period under observation[2]	
	Rainfall in inches	No. of rainy days	Rainfall in inches	No. of rainy days
April	0·69	6·3	0·00	0
May ..	2·59		0·35	1 (April–May: 2)
June	7·66	49·4	3·20	5
July	12·13		5·65	2
August	12·24		9·45	12 (June–October: 35)
September	9·33		3·35	10
October ..	2·80		4·20	6
November	0 07	0 5	0·00	0
December	0·11		0·00	0 (November–December: 0)
January	0·65	2·4	0 35	1
February	0·45		0 10	1 (January–February: 2)
March	0 37	—	0·10	1
Total	49·09	58·6	26 75	39

[1] From *Indian Weather Review*, 1902.
[2] Author's determinations.

A sharp division into a period of rains—June to October—and a dry period—October to June—is the chief characteristic. The rainfall during the dry period is far too little to support growth in itself. The growth which takes place throughout the greater portion of the year is therefore dependent on the moisture which the plant can derive from the soil The particular year under consideration is characterised by the lightness of the monsoon rains. This is a factor which must be taken into consideration in considering the values given below; but it seems improbable that the conclusions here drawn will be rendered invalid on this account.

(2) *Temperature* (° F.).

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Maximum	72·7	76·8	87·9	96·1	95·6	92·4	89·5	88·5	88·3	86·7	81·3	74·5
Minimum...	52·1	54·4	62·9	71·9	76·3	79·2	79·8	79·3	78·8	73·1	62·0	53·7

The above table[1], giving the monthly means of the maximum and minimum temperature, illustrates the main features with regard to the temperature. If this table be compared with that already given for the rainfall it is seen that there are three strongly-marked seasons which may be arranged as follows:—

(1) Cold weather......mid-October to March—low temperature, dry.
(2) Hot weather . ...March to mid-June—very hot and very dry.
(3) Rains..... ....mid-June to mid-October—hot and wet.

(3) *Humidity.*

The table given below[2] simply emphasises the conditions which are prevalent during the hot weather:—

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
71	63	54	52	62	76	83	84	82	75	70	73

The Relation of the Soil to Crops. It is not proposed to do more than touch upon this subject; and the point that it is most desired to bring out is best indicated in the case of indigo. In Behar, indigo is commonly sown in early March, when, from the table of rainfall, it will be seen that over four and a half months of practically rainless weather have preceded the time of sowing. Nevertheless, seed placed not an inch below the surface and without irrigation, will germinate. Nor is this the only point, for the young plant is capable of living and growing throughout the three intensely hot and dry months immediately following. Frequently this period passes without a drop of rain, and the plant is subjected during the day to the scorching west winds that are prevalent at this season.

Some idea of the conditions to which the young plant is subjected is given in the following table of soil temperatures:—

[1] From *Indian Weather Review*, 1902.
[2] From *Indian Weather Review*, 1896.

Soil Temperature (° F.)[1].

	Surface	2 inches	6 inches	12 inches
Germinative period:— 2 p.m. March 20th	121	86	73·5	69·8
Average for week— 2 p.m March 17th—March 23rd	117	84·5	72	69
Period of greatest heat.— 2 p m. May 17th	143·5	102	91·5	86
Average for week— 2 p m. May 14th—May 20th	138	102	92	87

A soil, in which not only will seed germinate, but which will support the young plant throughout the protracted period of intense heat and drought, must bear some peculiar property in its relation to moisture.

Methods of Cultivation. Here again the methods of indigo cultivation best indicate the desired points. In the case of this crop the cultivation is most thorough. Briefly, it is as follows:—

The land is thoroughly ploughed two or three times about the middle of October (immediately after cessation of the rains)

If the land be at all "heavy," the clods of earth are, in addition, thoroughly broken by hand, and in this way the surface soil is rendered exceedingly fine. It is then subjected to a process of compacting by means of a *maira*, a native implement which takes the place of a roller, and consists of a flattened log, to the two ends of which bullocks are yoked. The land is thus compacted at frequent intervals until the sowing period in early March. The moisture is by this time drawn up to the surface, and the seed is drilled in and pressed home by passing the *maira* again over the field. Germination takes place in 7—10 days. This method is entirely empirical on the part of the cultivator, but it seems worthy of some enquiry and explanation, for it is a remarkable fact that so much moisture can be brought to the surface in this way by the single process of compacting.

General Physical Properties. The soils which form the subject of the present note occupy an area of considerable extent, covering as they do a stretch of country some 800 miles in length, with a breadth varying from 50 to 150 miles. Throughout this area there is an unbroken stretch of alluvial lands, traversed by numerous rivers, which, after

[1] Author's determinations The complete series will be found in the "Report of the Dalsingh Serai Research Station, 1905."

leaving the hills, have a fall of between 6 and 9 inches in the mile. The beds of these rivers are some 20 feet below the general level of the surface, which latter extends for mile upon mile in a slightly undulating manner. The undulations are, however, very slight, and rarely reach a value of 10 feet. The depth of alluvial soil is, throughout the area, very considerable, and over the entire area extends below the level of the ground water. In texture the soil is remarkably fine, and broken only by stretches of a calcareous deposit known as *kankar*. These deposits occur quite irregularly, and at various depths. In the absence of mechanical analyses it is impossible to give any accurate measure of the size of the soil particles. It is known[1] that 97—98 per cent. of the soil will pass through a sieve with 80 meshes to the linear inch. A more abstract, but, perhaps, a more lucid, idea will be given, if it is said that the ultimate particles are so minute that, if rubbed dry between the fingers no sensation of "grit" is produced. Until definite mechanical analyses are made this description must suffice. As is usual with alluvial soils, considerable variation of character occurs, and the changes are frequently abrupt and quite irregular. Thus beds of clay occur which rapidly die out and may be replaced by a fine, light sand or by some intermediate type; but the point that it is desired to emphasize is, that all these variations take place within the limits of size of the soil particles above given.

(2) Scope and Methods of the Investigation.

At the commencement, the scope of the investigation was strictly limited to the determination of the moisture and temperature of the soil for the normal conditions under which indigo is sown, with the ultimate object of tracing some means of rendering these as favourable as possible; for, although the crop is normally sown at this season, a fact which, in itself, proves that germination is, as a whole, satisfactory—it is undoubtedly the case that a considerable annual loss takes place from failure in the germination or from subsequent withering due to lack of moisture.

It was soon found, however, that the moisture conditions were subject to such daily and seasonal variations that the scope had to be widened considerably to include a study of the causes which gave rise to these variations. Here, again, it was found impossible to draw a limit, and it became necessary to study in outline the general question

[1] Determination made by author.

of the relations of the soil moisture to the ground water, and of this, again, to the free water surfaces. It was found, for instance, that a considerable movement of the soil moisture was taking place, and that this movement was of such a nature that it must constitute a severe drain upon the reserve supply of ground water. A daily record of the fluctuations of a well was therefore instituted. The fluctuations so disclosed seemed barely sufficient to account for the observed facts, and a further comparison was made between the well level (level of ground water) and that of the free water surfaces (river, etc). The gradually expanding scope of the investigation, taken in conjunction with the short period devoted to the enquiry, necessarily led to a somewhat limited collection of data. They, however, point to the probability of several hitherto unrecognised conditions—possibly peculiar to these soils—the recognition of which, it is hoped, may help to a solution of some of the problems connected with them.

Methods. As the general texture of these soils admits of the employment of somewhat unusual methods in the determination of the various properties now to be considered, those methods finally adopted must now be considered in some detail.

Samples were all taken by means of an iron cylinder about 4½ inches in diameter, fitted loosely with an iron piston, which allowed the cylinder to be driven in to a depth of 8 inches exactly. The soil to one side of the cylinder is then removed, and the 8 inches column of soil isolated by the insertion of a *khurpa* (a flat trowel), and removed to the laboratory.

Soil moisture is now determined in the following manner:—In a cylinder of the above diameter the soil can be readily removed by means of the piston without appreciable compression of the superficial layers. One inch (the eighth inch) is first removed, and the soil rapidly and thoroughly mixed in a mortar. From this mixed soil approximately 10 grams is removed into a small glazed porcelain dish, which has been previously dried and weighed, and the weight accurately determined. A second sample, similar to the first, is taken in like manner.

A second inch is now removed and duplicate samples taken of it, and this process is repeated with each of the superficial eight inches contained in the original sample. This method of duplicate determination, therefore, gives 16 samples. The series of dishes is now transferred to a water-oven at 100° C., which is maintained at that temperature for from 4½ to 5 hours. The dishes are then removed to

a desiccator, cooled and weighed, after which they are again heated for 3 hours, and again cooled and weighed.

With regard to this procedure the following points may be noted. It is a procedure which relies solely on the minute size of the soil particles for its accuracy and practicability. That remarkably accurate results are obtainable will be apparent from the figures noted throughout this paper. It will be sufficient to give here two examples of the degree of accuracy obtainable.

Degree of Agreement between Samples

The following figures are chosen to show the range of accuracy obtainable, and are typical of the degree of error admitted:—

	Weight of moisture per 100 grams dry weight of soil					
	1	2	3	4	5	6
Sample No. 1 .	17·31	14 84	12·02	16·64	19·90	5·83
„ No. 2	17·31	14·92	12·11	16·55	20·12	5·50
Difference . .	0	0·08	0·09	0·09	0·22	0·33
Percentage error	0	0·5	0·8	0·5	1·1	5·7

The first five examples here given are typical of the errors accepted. An error, such as that given in the sixth example, is only accepted in the few cases where the determination was of a superficial layer of loose, almost dry soil. It is obvious that the same actual error is trebled when the percentage moisture falls from 15 to 5; moreover, such a dry soil consists largely of aggregates which are not readily broken down, and the loss of moisture which would take place during the time occupied in producing a thoroughly homogeneous mixture, will introduce a larger error than is now under consideration.

The Weight of Dry Soil contained in the Cylinder.

The total initial weight of the soil was determined by actual measurement, and the percentage moisture in each inch was then determined, and, from these, an average figure for the percentage moisture obtained. From these figures a simple calculation gives the

dry weight. The following table gives the most divergent results obtained in numerous determinations:—

	Date	Actual weight	Average moisture	Dry weight	Difference	Percentage error
1st determination	Dec. 4	2522	10·94	2245·5	84·5	3·6
2nd ,,	,, 23	2573	10·01	2329·0		

The method, owing to its indirectness, is not one that admits of general adoption, and the chief reason for its use was the comparative ease with which small samples can be handled. Its accuracy is nevertheless sufficient, for it must be noted here that the land had twice during this season been "compacted," a process which must naturally raise the weight of soil in the superficial 8 inches. The error due to the method of experiment and calculation is therefore certainly less than that given.

The second point to be noted in this procedure is the use of the temperature of 100° C., for drying. This was adopted in place of the more usual 110° C., as a matter of convenience. Preliminary experiments had shown that the increased loss due to the use of the higher temperature did not exceed 0·005 gram on 10 grams soil.

Details of the Investigation.

(A) *Specific Gravity* This was determined from samples of soil dried in the following manner:—

The soil is first air dried and then reduced to fine powder in a mortar after which it is dried in a water-bath of 100° C., for four hours. It is then cooled in a desiccator and transferred to a dry tube when cool.

A known weight of about 10 grams of this soil is boiled with water in a small flask. After cooling to 60° C., it is transferred to the specific gravity bottle and weighed.

Each determination is controlled by a second determination in which an unknown weight of soil, prepared and boiled as before, is transferred to the specific gravity bottle. The bottle is weighed and the contents are then transferred to an open dish, evaporated to dryness over a water-bath, and finally dried for four hours at 100° C., in a water oven. The dish is then transferred to a desiccator, cooled and weighed. The two figures in all cases agree within an error of 1·5 per cent.

A series of determinations was thus made for each of the eight superficial inches, and the average of the duplicate determinations is here given:

Specific Gravity.

	Surface to 1 inch	1—2 inch	2—3 inch	3—4 inch	4—5 inch	5—6 inch	6—7 inch	7—8 inch
Specific gravity	2·716	2·715	2·713	2·710	2·706	2·736	2·734	2·734
Average ..	2·713				2 735			

The chief point of interest in the above table is the abrupt rise of specific gravity below the 5th inch, the increase being 0·022. So far no recorded parallel has been traced. The cause may possibly be found in the native plough, which penetrates to this depth. At least once each year the lands are thoroughly ploughed several times in each direction, but the soil is not inverted. It is possible to conceive that this repeated loosening accompanied by percolation of rain would silt out the particles of higher specific gravity from the superficial soil.

(B) *Apparent Specific Gravity.* For this determination a cylinder of known internal diameter and 8 inches in length was used The methods by which the dry weight of soil contained in the cylinder was determined have already been detailed and need not be repeated here. From this figure the apparent specific gravity of the superficial 8 inches of soil is readily calculated. In these determinations a break is apparent at the 4th inch, showing the more compact nature of the soil below that depth. It will be convenient, however, to consider the superficial 5 inches together, since, as has already been shown, the increase in the actual specific gravity occurs here.

The following figures will indicate the range of value obtained for the apparent specific gravity:—

	8 inch—6 inch		5 inch—top		Total, 8 inch—top	
	Dec. 4	Dec. 23	Dec. 4	Dec. 23	Dec 4	Dec. 23
Total weight (gr.)	996	1024	1526	1549	2522	2573
% moisture	11·71	12·63	10·48	7·40	10·94	10·01
Dry weight (gr.)..	879·37	894·67	1366·07	1434·37	2245·44	2329·04
Volume (c.c.)	649·99		1091·85		1741 84	
Sp. g. (apparent)	1·351	1·376	1·255	1·315	1·302	1·345
Difference .	0·25		0·52		0·43	
% error..... ..	1·8		4·0		3·2	

As has been already explained, these differences are, at least partly, due to the cultivation of the field during the intervening three weeks. A control determination, taken on Dec. 4th, gave the total dry weight as 2237·4, and the specific gravity (apparent) as 1·284, or a working error of 1·4 per cent.

(C) *Weight of Soil per Acre.* This is merely a calculation from the apparent specific gravity. For these lands the weight of dry soil per acre of a layer 8 inches deep is approximately 2,400,000 lbs. The exact value for the superficial 8 inches will, of course, depend to some extent on the condition of cultivation. Thus in the sample taken on Dec. 4th the value is 2,360,253 lbs., while that for Dec. 23rd is 2,438,423 lbs., the mean being almost exactly 2,400,000 lbs., which figure may be taken as the average weight of soil in an acre calculated as 8 inches deep.

(D) *Volume of Interstitial Space.* The figure representing the volume of the interstitial space is most important, since it will indicate the maximum volume of water which could be contained in saturated soil. For this reason the value should be calculated from the values obtained for the 6th—8th inch inclusive. These will approximate more nearly to the true value for the bulk of the soil. Calculated in this manner the most divergent values obtained were:—

$$\left.\begin{array}{ll}(1) & 50{\cdot}3 \\ (2) & 49{\cdot}4\end{array}\right\}\text{ average } 49{\cdot}8.$$

Roughly, therefore, the interstitial space may be considered as equal to one-half the volume of the soil.

(E) *Saturation Value.* By this is meant the number of grams of water contained in the saturated soil, the dry weight of which is 100 grams. Throughout the following pages the figures representing moisture percentages are calculated on the dry weight. This value has not been determined experimentally, it can, however, be readily calculated from the above figures. It has been shown that the interstitial space is approximately 50 per cent., while the specific gravity (actual) of the soil is 2·755. This is equivalent to 36·6 per cent. moisture on the dry weight of soil.

(F) *Movement of Soil Moisture.* This question is a very wide one, and the determinations now detailed only touch on the very margin of the subject. They seem, however, to indicate that this movement assumes very large proportions in these soils. The methods by which the determination of the value of soil moisture was made have already

been detailed. It will be necessary here, therefore, only to note the general mode of investigation.

The experiments consist of two series which were carried out concurrently. In the first of these a particular area of land was submitted to various methods of culture, and the effect of these on the moisture content of the superficial 8 inches determined from samples removed at intervals. This series was commenced immediately after the cessation of the rains in October, and continued until the following February.

In the second series the moisture in the land at different stages of cultivation was determined (*a*) in the early morning, (*b*) about 2.30 p.m., the two samples in all cases being taken as near as possible to each other to reduce to a minimum the errors introduced by lateral variations in the value of soil moisture.

Clearly the first point to determine is the behaviour of moisture in uncultivated land. For this purpose a field was, shortly after the commencement of the rains, allowed to go out of cultivation after a preliminary course of thorough ploughing and levelling. In this condition it remained until the end of the rains, and received the last rain on October 7th to 9th, between which dates 2·85 inches of rain fell.

Moisture determinations were made on the following October 10th, and again on October 17th, October 23, and November 21st, the only rain received during the period was 0·3 inches, which fell on October 30th; the field throughout the period remained untouched.

The following table shows the values obtained:—

Percentage of Water in Soil Samples.

	8th inch	7th inch	6th inch	5th inch	4th inch	3rd inch	2nd inch	Top inch
Rains ended Oct. 9th								
Determination of Oct. 10th	21·75	20·97	20·60	20·01	20·57	20·59	20·94	21·12
,, ,, ,, 17th	19·56	17·27	15·37	14·35	13·29	13·33	12·29	9·35
,, ,, ,, 23rd	19·23	16·33	14·14	12·62	12·21	11·91	11·07	8·96
,, ,, ,, 30th	0·3	rain fell	—	—	—	—	—	—
,, ,, Nov. 21st	13·23	13·18	13·32	11·85	9·83	9·00	8·13	5·84
Loss during period Oct. 10th—Nov. 21st	8·52	7·79	7·28	8·16	10·74	11·59	12·81	15·20
Average loss... .... 10·26								

This is equivalent to a total loss of 210 tons of water per acre, or an average daily loss of 4 tons per acre.

That this figure should represent the actual loss per acre during the period is highly improbable, and an attempt was accordingly made to obtain a nearer approximation to the real value.

The percentage of water at a given point is never stationary, and its amount must be considered as the value which results from the simultaneous action of two natural causes, (1) the motion from that point in the direction of the surface, to replace the water removed by the evaporation influence of the air, and (2) the passage of water to that point from a lower level. It must be borne in mind that these processes may be reversed as the result of heavy rain, and the motion will then take place in the opposite direction. The following table will, however, show that in these soils the important motion is that given above. On the 23rd October two determinations were made: the first of these from a sample taken at 8 a.m, at which time evaporation had barely commenced, the second from a sample taken at 2.30 p.m., shortly after the heat of the day had passed and when evaporation might therefore be supposed to have reached a maximum:

Percentage of Water in Soil Samples.

	8th inch	7th inch	6th inch	5th inch	4th inch	3rd inch	2nd inch	Top inch
Morning sample	19 23	16·33	14 14	12 62	12 21	11·91	11·07	8 96
Afternoon sample	15·60	14·39	12·74	12 21	12·11	11·39	9·86	4 93
Loss	3·63	1·94	1·40	0·41	0·10	0·52	1 21	4 03

It will be evident from this table that the moisture lost during the day is replaced from below, in greater part, during the night.

The table also gives a close approximation to the correct value of the total daily loss. It is equivalent to a loss of 1·66 per cent. of dry weight, or 17 8 tons per acre. This is very much in excess of the figure previously obtained, and indicates a considerable recuperative power.

This figure, again, cannot be considered more than an approximation, and it is not yet apparent what the true value of the daily loss is. The following reasons briefly indicate that the loss must be in excess of this figure:—

(1) The figure obtained is the actual loss only, it must be remembered that the upward motion of the water is a continuous process

which only becomes apparent at night, when evaporation is slight or non-existent.

(2) The second (afternoon) is taken at 2.30 p.m., when evaporation is at its maximum. Evaporation will not cease till evening (about 6 p.m.), and this latter amount is omitted from the calculation.

(3) From the above figures it is obvious that the loss is not restricted to the superficial 8 inches, and, probably within a short distance, it would appear to be increasing with the depth.

There is here sufficient reason for supposing that, in taking the above figure—17·8 tons per acre—as the daily loss, the calculations based on it will not be open to the charge of exaggeration.

It is apparent from the figures given here that there is in these soils an enormous capability for raising water to the surface, though it is not possible at present to give an exact measure of it. The recognition of this upward motion is so important that a further proof of its existence will be given.

It has already been shown that a field, which is not tilled, rapidly and consistently loses moisture. The cause of this is to be found in the fact that there is a complete continuity of soil particles up to the surface. There is no abrupt rise in the volume of the interspaces such as occurs about the 5th inch when the land is cultivated with the native plough. Consequently the flow of moisture from below to the surface receives no check. The effect produced by introducing such a break in continuity was the next point of enquiry. For this purpose the field was put under the system of cultivation normally adopted when indigo is to be sown, and which has been briefly described above. The field, which had up to November 21st remained untilled, was ploughed and levelled with the *maira* on 22nd, and again compacted with the *maira* on December 22nd and the moisture determined. Though the cultivation was delayed until very late, and the land had in the meanwhile been allowed to lose a large amount of the original moisture, it was by this time approaching the condition of indigo lands. These figures are now given:—

Percentage of Water in Soil Samples.

	8th inch	7th inch	6th inch	5th inch	4th inch	3rd inch	2nd inch.	Top inch
Determination of Nov. 21st	13·23	13·18	13·32	11·85	9·83	9·00	8·13	5·84
„ „ Dec. 22nd	15·14	14·19	14·11	11·72	9·66	8·20	7·23	3·54
Gain or loss	+1·91	+1·01	+0·79	−0·13	−0·17	−0·80	−0·90	−2·30

The result of cultivation has been a total loss equivalent to 0·07 per cent. of dry weight from top 8 inches. The figures, however, show that the loss is confined to the superficial 5 inches as the result of loosening the soil. Below this there is a marked rise, the value of which increases with the depth. The condition of the field is obviously much more satisfactory, but the chief point to be noticed is that the increase is due to a rise of moisture from the lower layers of the soil.

An examination of the figures for December 22nd shows no marked break in the diminution of soil moisture as the surface is approached. The diminution is gradual, and requires a comparison with previous figures to make the break at the 5th inch apparent. It appeared, therefore, that an effective break had not been introduced, and a further attempt was made to do this. For this purpose the land was ploughed four times, and finally a *maira* lightly run over the surface to level without compacting the soil. The surface soil was reduced in this way to a very fine and practically air-dry condition, which, it was anticipated, would form an adequate check to evaporation. On the morning of January 18th, rain began to fall, and a sample was therefore taken and a moisture determination made. Previous determinations are quoted for comparison:—

Percentage of Water in Soil Samples.

	8th inch	7th inch	6th inch	5th inch	4th inch	3rd inch	2nd inch	Top inch
Dec. 19th, field ploughed and levelled								
Determination of Dec. 22nd	15·14	14·19	14·11	11·72	9·06	8·20	7·23	3·54
,, ,, Jan. 18th	21·58	16·23	13·80	10·85	9·33	7·27	4·36	7·52
Gain or loss	+6·44	+2·04	−0·31	−0·87	−0·83	−0 93	−2·87	+3·98

Here, again, the superficial inches show a loss (the gain in the top inch being due to a rain falling at the time the sample was taken). The 7th and 8th inch, however, show a large increase in the moisture content, equivalent to 4·24 per cent. of the dry weight. This rise is due to the reduction of evaporation, which is now so small that the upward flow can more than compensate for it. It must further be noted that the moisture contained in the 8th inch is now equal in amount to that contained by this inch the day after a three days' rain had ceased. In the meantime three months had elapsed, broken only by a single shower of 0·3 inches—three weeks after the commencement of the experiment.

If there be needed further proof of an upward flow which is capable —in the presence of only slight evaporation from the surface—of maintaining the moisture at a value which is 60 per cent. of the saturation value, and, in the presence of excessive evaporation, very largely replacing during the night the moisture lost by evaporation during the day, it will be found in the fact that it became possible by altering the methods of cultivation, to reduce and increase at will and within wide, but so far indefinite, limits the moisture in the field. Sufficient has, however, been said to show that an upward flow of no mean order appears to be the rule in these soils.

From the figures given in the above lines it is apparent that there must be a drain of no mean order upon the moisture retained in the soil, and it becomes a matter of interest to trace to its source the supply from which this movement emanates. To a small extent, data bearing upon this problem have been accumulated. Though suggestive, their range is necessarily small, and insufficient to throw any very direct and definite light upon the subject. These preliminary notes upon one branch of the problem are now communicated in anticipation of the occurrence of an early opportunity for a renewal of the investigation upon the wider aspect. Until such opportunity occurs for dealing with this more fully the data and their interpretation must remain incomplete.

Conclusion.

The points on which an attempt has been made to lay emphasis may be summed up as follows:—

(1) A large daily evaporation is taking place from the surface of the soil.

(2) This evaporation is entirely, or in greater part, counteracted by a large upward flow of moisture from a lower level and ultimately from the ground water.

Sufficient has been said throughout the course of the paper to show that the question is one of considerable practical importance, and it is unnecessary to dilate further on this aspect. Further work will alone decide the questions which have been indicated; possibly the more serious omissions in the above series of observations are to be found in the absence of mechanical analyses, and in the complete lack of observation of the value of soil moisture at a greater depth than 8 inches.

MECHANICAL ANALYSIS OF SOILS.

The Method adopted by the Chemical Committee of the Agricultural Education Association.

THE object sought in mechanical analysis is to obtain an approximate estimate of the proportion in which particles of different sizes are present. It is pretty certain that in the case of the inorganic materials the size of the particles has a predominant influence on the physical and mechanical properties of the soil.

That is to say it may be fairly assumed that the effect of the various mineral substances present (with the exception, perhaps, of calcium carbonate) on the physical properties of the soil is far more dependent on the size of the particles than on their chemical nature.

At the same time it must be remembered that the mechanical texture and other physical properties of the soil will be profoundly affected also by the amount of organic matter present, and in regard to this constituent of the soil questions of the size of the particles are of less importance.

The minuter particles of the soil appear to be held together more or less closely by quasi-chemical as well as by more strictly physical forces, and as this coagulation is in part due to humus, it is needful to remove the humus, before or during the process of mechanical analysis. The humus in combination with bases in the soil should be liberated by preliminary extraction with dilute acid. This at the same time removes the calcium carbonate, which on the whole must be regarded as an advantage.

By this treatment with weak acid and subsequent extraction with ammonia all coagulation due to humus or calcium carbonate is destroyed, and the inorganic particles of the soil are set free from the temporary aggregations which may have been brought about by cultivation, yet the attack is not drastic enough to materially affect the sizes of the particles considered as individuals. The object is to ascertain the ultimate

inorganic structure of the soil, for example to show the essential identity in mineral structure of the soil of a pasture and an adjacent arable field on the same formation; leaving the analyst to judge from the variation in the proportion of humus, &c., what will be the difference at the time of sampling in the physical properties of the two soils. The treatment also serves to remove the potent flocculating and deflocculating effects of small quantities of salts in the soil.

It is evident, however, that a method based on the foregoing preliminaries cannot apply to soils of which a large proportion consists of the very materials (humus or calcium carbonate) that have been removed. In other words, the method is of only limited application to soils mainly composed of organic or calcareous matter.

While it is convenient to attach names to the various fractions into which the soil is divided by a mechanical analysis, instead of being continually forced to specify the limits of size, yet a very restricted choice of terms is available, nor have these always been used in the same sense by different experimenters. The terms used in the scheme below are in common use in connexion with the particles of earthy materials, are well understood, and convey the idea of gradation in size.

The term "Soluble Humus" is used to denote the organic material soluble in dilute ammonia after the soil has been washed with acid.

General Principles of the Method.

The soil (*i.e.*, air-dried fine earth, which has passed a 3 mm. sieve) is allowed to remain in contact with dilute hydrochloric acid, N/5 HCl containing 1 gram-molecule in 5 litres, until effervescence ceases. It is then washed on a filter until all acid is removed.

The solid residue is now well rubbed up by means of a rubber pestle (made by sticking a glass rod as handle into an inverted rubber stopper) with dilute aqueous ammonia and, after removal of the coarser particles by sieves, separated into fractions by the beaker method of sedimentation. Lipped beakers of approximately the same size and shape are provided with a strip of paper at the back, marking a particular height. In these the material is well rubbed up with the rubber pestle, the water brought up to the mark, thoroughly agitated and the pestle removed. The beaker is now allowed to stand for a given time and the turbid liquid is poured off into another beaker. The particles which had fallen to the bottom of the beaker are again worked up with the rubber pestle in the dilute ammonia, and the operation of settling for

the same time from the same height is repeated. When the operation has been repeated 8—10 times it will be found that the whole of the particles A within the beaker settle down within the given time, whereas the particles B which have been poured off are too small to fall through the given height in the time chosen. By taking a shorter time or a greater height particles A can be further subdivided, as also particles B, by choosing a longer time or a lesser height.

The individual analyst can arrange times or heights to secure a group of particles lying within any desired limits of size using the microscope to check the grade of sediment which is being attained. The order in which the different elutriations are carried out is also a matter of convenience.

In order to secure uniformity, and that the results of different analysts may be comparable, it is recommended that the following limits of size for the various groups of particles be adopted, and that any worker using a smaller number of groups will still make his division at the suggested limits, so that one of his groups may include exactly two or three of the specified groups.

The limits given below can only be looked upon as approximately exact. Whatever limits are fixed a little overlapping of the different divisions will always be found.

	Diameters in millimetres		Proposed Name	
	Maximum	Minimum		
Stones and Gravel ..	—	25	Stones	Separated by Sifting
	25	10	Small stones	
	10	3	Gravel	
Earth..	3	1	Fine gravel	
	1	·2	Coarse sand	
	·200	·040	Fine sand	Separated by Subsidence
	·040	·010	Silt	
	·010	·002	Fine silt	
	·002	—	Clay	

The above substances should all be weighed after drying in the steam-oven; it is useful to give, also, the weight after ignition.

On the next page details are given of a method of procedure for carrying out this process.

It is desirable that as many measurements as possible should be accumulated of the sizes obtained by sedimentation for particular periods and various depths of falling, as the correspondence between the periods specified and the above sizes is only approximate as yet.

METHOD OF ANALYSIS.

1. 10 grams of the air-dry earth which has passed a 3 mm. sieve are weighed out into a porcelain basin and worked up with 100 c.c. of N/5 hydrochloric acid, the acid being renewed if much carbonate of lime is present. After standing in contact with the acid for one hour the whole is thrown upon a dried, tared filter, and washed until free of acid. The filter and its contents are dried and weighed. The loss represents hygroscopic moisture and material dissolved by the acid.

2. The soil is now washed off the filter with dilute ammoniacal water on to a small sieve of 100 meshes to the linear inch, the portion passing through being collected in a beaker marked at 10, 8·5 and 7·5 cm. respectively from the bottom. The portion which remains upon the sieve is dried and weighed. It is then divided into "Fine Gravel" and "Coarse Sand," by means of a sieve with round holes of 1 mm. diameter. The portion which does not pass this sieve is the "Fine Gravel." This should be dried and weighed. The difference gives the "Coarse Sand." If required both these fractions can also be weighed after ignition.

3. The portion which passed the sieve of 100 meshes per linear inch is well worked up with a rubber pestle, and the beaker filled to the 8·5 cm. mark and allowed to stand 24 hours. The ammoniacal liquid which contains the "Clay" is then decanted off into a Winchester quart. This operation is repeated as long as any matter remains in suspension for 24 hours. The liquid containing the "Clay" is either evaporated in bulk, or measured and, after being well shaken, an aliquot portion taken and evaporated. In either case the dried residue consists of "Clay" and "Soluble Humus." After ignition the residue gives the "Clay," and the loss on ignition the "Soluble Humus."

4. The sediment from which the "Clay" has been removed is worked up as before in the beaker, which is filled to the 10 cm. mark and allowed to stand for 100 seconds. The operation is repeated till the "Fine Sand" settled in 100 secs. is clean, when it is collected, dried and weighed.

5. The turbid liquid poured off from the "Fine Sand" is collected in a Winchester quart, or other suitable vessel, allowed to settle and the clear liquid syphoned or decanted off. The sediment is then washed into the marked beaker and made up to the 7·5 cm. mark. After stirring, it is allowed to settle for 12½ minutes, and the liquid decanted off. The operation is then repeated as before till all the sediment sinks

in 12½ minutes, leaving the liquid quite clear. The sediment obtained is the "Silt" which is dried and weighed as usual. The liquid contains the "Fine Silt" which, when it has settled down, can be separated by decanting off the clear liquid, and dried and weighed.

6. Determinations are made of the "Moisture" and "Loss on Ignition" of another 10 grams of the air-dry earth. The sum of the weights of the fractions after ignition plus loss on ignition plus moisture plus material dissolved in weak acid should approximate to 10 grams.

7 It is advisable to make a determination of the "Fine Gravel" in a portion of 50 grams of the air-dry earth. The soil should be treated with acid, as in 1, and after that is removed by decantation may be at once treated with dilute ammonia and washed on the sieve with 1 mm. round holes. The "Fine Gravel" left on the sieve is then dried and weighed, and the percentage found should agree with that found in 2. If it does not the result now found should be taken as the true one.

CORRESPONDENCE.

MENDEL'S LAWS OF INHERITANCE AND WHEAT BREEDING.

In a paper dealing with the application of Mendel's Laws to wheat-breeding, I described a series of experiments which led me to conclude that immunity and susceptibility to the attacks of yellow rust form a pair of "characters" in the Mendelian sense of the word[1]. The data were obtained from a single experiment, yet I felt that the only course open to me was to publish them at once, leaving the discussion of the problems this conception opens up until further evidence was available. One of the objects I had in view in planning this particular part of the work was to determine whether there was any real hope of obtaining satisfactory rust-resistant wheats. From the breeder's point of view it appeared to me that if the mycoplasm hypothesis is true, *i.e.* if the young plant actually inherits the rust itself from its parent, this is not a promising line of research. Setting aside, therefore, for the time being any other views as to what constitutes immunity, I examined my results in the light of the mycoplasm hypothesis. As I pointed out, this failed to account for the fact that an immune wheat when crossed by a susceptible one gave rise to a susceptible progeny, though it was sufficient to explain the susceptibility of the hybrid obtained as the result of the reciprocal cross. I further speculated on the possibility of the generative nuclei bearing the hypothetical mycoplasm.

Butler, in a recent paper[2], criticises my conclusions, and considers that they have no bearing on the mycoplasm hypothesis.

The following excerpts from Eriksson's latest publication on the subject of the mycoplasm hypothesis will, I think, save me from the necessity of discussing Butler's arguments in detail, and show that my criticism was not altogether irrelevant: "Wie die Sache jetzt liegt, scheint es mir gar nicht unmöglich oder unsinnig zu sein an eine

[1] Biffen. *Journ. Agric. Science*, Vol. I. p. 40.

[2] Butler. *Journ. Agric. Science*, Vol. I. p. 361.

Erblichkeit der Krankheitsanlage auch dass männliche Organ, die Pollenkörner, zu denken," and further, "... so hat man wenigstens mit der Möglichkeit zu rechen, dass auch die Gewebe der Staubblätter, und zwar speziell die der Antheren, mycoplasma führend sein können[1]."

It is difficult to treat in detail one of the broad questions raised by Butler for lack of evidence one way or the other. It may at once be stated, however, that it is a well-recognized fact that immunity to yellow rust does not necessarily imply immunity to any other rust. Michigan Bronze, for instance, is intensely susceptible to yellow rust, but practically immune to black and brown rust. An inspection of the tables in Eriksson's *Die Getreiderost*[2] will provide numerous other examples.

But the question as to how far characters alter with a change of locality is still an open one, which can only be answered by the cooperation of a number of workers in different districts. Its importance is so obvious that it may serve a useful purpose if I point out some of the typical difficulties already encountered in this part of the research. Butler's paper provides two examples out of the three he quotes as illustrating this possibility. The first is "the striking case of spelt wheat which has proved very resistant in some parts of India and not in others." Spelt wheat is a generic term, for there are a large number of varieties of spelts in cultivation. Thus in my own experiments I have had occasion to grow nearly thirty, some of which were obtained from India. Amongst those are some varieties which are the most immune to yellow rust I possess, whilst others are second only to Michigan Bronze in susceptibility. If, as I suspect, the evidence for this particular case rests on a generalization from the various spelt crops as seen here and there in the country it is of no particular value. To be satisfactory it would have to be based on a critical experiment with one variety distributed over various districts and kept under observation for a number of seasons. Of such an experiment I can, however, find no mention.

The second example is provided by the rust resistant hybrids raised by Farrar in New South Wales, which have proved susceptible in India.

The question which at once arises is "Were they ever rust-resistant?" Had such varieties ever been tested for a sufficient number of years in Australia before being tried in India?

One has to be critical on such a point, for a variety of wheat may escape rust for a season or two and then, owing to conditions of which

[1] Eriksson. *Arkiv för Botanik.*, 1905, Bd. 5, p. 54.

[2] For wheats, p. 333 *et seq.*; for barleys, p. 344 *et seq.*

we are ignorant, become badly attacked. That this has been the case with Farrar's hybrids is clear. Thus in a communication referring to the hybrid "Bobs," Farrar writes[1], "I mentioned that it was rust-free in 1903 at the Hawkesbury College Farm, and it was on that account that I suggested that we might have in it a variety which would prove to be safe to grow in the coastal counties. In 1904, however, 'Bobs' failed to resist this pest at Richmond as well as other places in the county of Cumberland, but was in fact smitten hip and thigh by the pest.. .... Still the matter is disappointing; but it is nothing more, and this failure cannot be regarded as a final failure to get varieties which will withstand rust in the coastal counties."

Of the third case, that of *Kathia* wheat, I can find no further data as to its behaviour outside of the United States, but I think that enough has been said to make one cautious of the statement so frequently made that characters will alter with a change of locality. That physiological characters do so is clear in certain cases, but we badly need really definite evidence on this point with regard to rust-resistance.

R. H. BIFFEN.

THE SUPPLY OF NITRATE TO THE SURFACE SOIL FROM THE UNDERGROUND WATER.

IN Mr A. D. Hall's interesting paper on the "Fertility of Land allowed to run wild[2]," he attributes a part of the accumulated nitrogen to "capillary creep" of nitrates from the underground water. In the present very imperfect state of our knowledge as to the actual velocity at which water moves vertically through the soil during dry weather, together with a corresponding absence of exact information regarding the diffusion of salts in the soil, it would be impossible to prove the truth of Mr Hall's assumption. But there are several arguments of a circumstantial nature, which may be advanced to disprove it.

In the first place these underground waters will contain chlorides as well as nitrates, and if the one be brought to the surface in the manner suggested so must the other. I do not know of any analyses of Rothamsted well waters, but usually such water contains at least

[1] Farrar. *Agric. Gaz. of N.S.W.*, 1905, p. 262.
[2] *Journ. Agric. Science*, Vol. I. p. 241.

several times as much chloride as nitrate, and indeed the disparity is commonly very great.

Mr Hall naturally does not suggest that any particular portion of the accumulated nitrogen in the soils is due to the underground water, but from the fact that this source is mentioned at all it is to be assumed that a *material* part of the whole is meant. Assuming such to be one-tenth, it would mean that of the ·037 per cent. increase of nitrogen in the surface soil of the Broadbalk field, ·0037 is referable to the supply in question, or of the ·023 per cent. accumulation in the Geescroft surface soil, ·0023 per cent. is from the same source. There is no need to consider the gains of nitrogen in the lower depths of the soil for the purpose in view.

If this underground water contains equivalent quantities of chloride, then there should be a similar accumulation of chlorine; or if, as is much more probable, the ratio of chlorine to nitrate-nitrogen in the underground water is 10 : 1 or even a wider ratio, then the accumulation of chlorine should be, say, $·0037 \times 10 = ·037$ or $·0023 \times 10 = ·023$ respectively. On this point Mr Hall's paper gives no information.

The quantity of chlorine in the Broadbalk and Hoos fields soil is, however, stated in the Lawes Agricultural Trust lectures by Dyer[1], and there is, as a matter of fact, in the Broadbalk field somewhat more chloride in the second depth of 9 inches than in the lower strata. The difference varies from one part to eight parts per million of soil, and for most plots it is only two or three. Eight parts per million is equal to ·0008 per hundred of soil, and if only the unmanured plots are considered the quantity falls to ·0001 per cent. chlorine. In the Hoos field there is no such increased quantity of chlorine in the second depth.

This is far smaller than the quantity of chloride which should be found if any material portion of the accumulated nitrogen in the uncultivated patch of Broadbalk field had been derived from underground water.

As a matter of fact there is no reason for supposing that the larger quantity of chloride in the second 9 inches of soil in the Broadbalk field was derived at all from underground water. The higher concentration in this depth is much more readily explained by the effects of season.

Then, too, if salts pass from the underground water to the surface and accumulate there, it means that on the whole a greater quantity of

[1] United States Department of Agriculture, Office of Experiment Stations, *Bulletin* No. 106, 1902.

salt moves annually in this direction than downwards. If this is so it follows that a greater quantity of water does likewise, and that there is a net loss of underground water, or in other words that the underground water is not derived from percolation at all but from some other source. It is, however, well established that in many or most situations the underground water is due solely to percolation.

There are also other arguments which may be advanced against the assumption that salts ever reach the surface from underground water, unless the latter is within 3 or 4 ft. of the surface.

One is that in any country with a rainfall distributed well over the year as in England, percolation is in progress more or less all the year through; such movement of water is much more rapid than the opposite one; and the resultant effect must be a general downward movement of the salts rather than the converse. Even in India, with five or six months of dry weather and a much higher temperature than that of Europe, it is not usual to find any accumulation of salts in the surface soil where the underground water contains high proportions of nitrates and chlorides. For, example, the very saline well waters of Gujarat[1], and Muttra[2] are situated below very fertile and non-saline soils. *Usar* land is not here forgotten, but this special case does not negative the more common one. If the underground water happens to lie less than about 5 ft. from the surface, such an accumulation may occur, but these conditions are exceptional.

Again, the fact that the amount of evaporation is the same from the 20″ and 60″ gauges at Rothamsted is a proof that the underground water supply does not affect the amount of water evaporated, for if it did the 60″ gauge should lose more than the 20″ gauge.

If the absence of accumulated chlorine were accounted for on the assumption that both this element and the nitrate do come with the underground water during dry weather, when the nitrate is arrested by vegetation, but that later with the next rain the chlorine is washed down again, such an argument implies that this can happen during such short dry periods as are experienced at Rothamsted; that also the whole of the water in the soil down to the underground water also passes in the same short period to the surface (and evaporates), and that during the next wet period enough rain falls to wash down again the accumulation of chloride and other salts to their original position at the underground water level. Such an assumption implies a movement

[1] *Vide Agricultural Ledger*; No. 14 of 1895.

[2] *Vide Transactions of the Chemical Society*, Vol. LXXXI.

of water far greater than actually occurs. Admittedly this velocity is not known with any great precision, but even the most extravagant of the various laboratory experiments which have been made to exhibit the rate of rise of water through soils, have not shown such a velocity as the foregoing case would require.

J. WALTER LEATHER.

I agree with Dr Leather that capillarity would bring up chlorides as well as nitrates, but on the first rainfall sufficient to cause percolation down would go the chlorides again, the nitrates having meantime been taken up by the crop. Mr Warington has shown[1] that such returns of nitrate from the subsoil to the surface can take place. It is, however, arguable that capillary uplift will only bring back to the surface nitrates which had been made there and then washed down, but this ignores all possibility of diffusion or of lateral displacements of the whole body of soil water. How otherwise does a tree in a paved street get its nitrogen except by the lateral influx of nitrates in the soil water?

A. D. HALL.

[1] *Trans. Highland and Agric. Soc.* 1905.

REVIEW.

The Book of the Rothamsted Experiments. A. D. Hall, M.A. [John Murray, Albemarle Street, London, W.] Those who were privileged to associate personally with Lawes and Gilbert on the scene of their labours will recollect that a walk over the farm or through the Park with either of them—perhaps more especially with Lawes—seldom failed to be conversationally suggestive of how much potential knowledge remained still unextracted from the materials they had accumulated. Of the materials themselves much yet remains to be given to the world; but even of the immense mass of work that has been actually recorded and developed by full discussion in the long array of memoirs proceeding, directly and indirectly, from Rothamsted, much has appealed very little to those outside of the circle of advanced and diligent students, owing, perhaps, to the fact that the recorders devoted themselves rather to the accumulation and record of knowledge than to its popular diffusion. Indeed, it has long been a matter of regret that, leaving aside the earlier broad generalisations that have become commonplace knowledge, so great a part of the fruit of sixty years' work has remained more or less hidden from a large section of the contemporary generations of those on whose behalf it was carried out.

The work, of course, has not been without its popular exponents, some of whom have taught through books, some through journals and newspapers, some from behind the lecture-table, and some by all three methods, and, of very necessity, all current treatises on agricultural chemistry are based, as regards not a small portion of their contents, on the Rothamsted results. Dr Fream's little book, now, however, 17 years old, formed a popular guide to the wheat, barley, and grass experiments; much has been done by Mr Warington—whose own classical work on nitrification, as readers will scarcely need to be reminded, was carried out in the Rothamsted laboratory; and many

others have also lent their aid in presenting the Rothamsted results to those who lacked time or energy to consult the original papers. The subject of nitrification, for instance, was ably and popularly treated by Mr Warington in the first series of American Lectures; but these are now out of print. Gilbert, in the second series of American Lectures, republished at home, gave a general review of much of the work, though scarcely in a form likely to appeal readily to readers of scant leisure. But until now we have lacked a really concise and—if the word may be pardoned—lively monograph presenting a general view of the whole field such as would enable an agricultural student who has been able to devote but a limited time to chemistry to make an all-round acquaintance with what has been done at Rothamsted, and such as would at the same time give to the practical farmer some grasp of the immediate import of the Rothamsted work in relation to the operations which he has to plan and direct in his everyday life.

It may be fairly said, however, that such a book is now before the public.

When Mr Hall succeeded to the directorship of the Rothamsted station, he realized that he had a duplex task before him. There was the work of investigation, to be continued on the lines marked out by his illustrious predecessors, and extended in new directions indicated by the progress of modern knowledge and the requirements of the times. But there was also the work of popular diffusion, not only of what should be, but of what already had been, done. This task he has taken up with the ardour and ability which were expected from him by those who knew his enthusiasm and experience as a teacher; and this book forms an important contribution to its fulfilment.

The excellent biographical sketches of Lawes and Gilbert, written by Mr Warington, which appeared in the obituary notices of the Royal Society, are reproduced as a fitting introduction, and the book is divided into thirteen chapters, dealing respectively with the investigations relating to the sources of the nitrogen of vegetation; with the meteorological observations; with the composition of the Rothamsted soil; with the experiments on wheat, on barley, on oats, on root crops, on leguminous crops, on grass, and on crops grown in rotation; with the feeding experiments, and with such miscellaneous enquiries as those relating to sewage irrigation, to the relative nutritive value of malt and barley, to ensilage, and to the composition of the wheat grain and its milling products.

In summarising and illustrating many of the results, Mr Hall has

followed what, in relation to Rothamsted, must be regarded as the new departure already made in some of his published papers, in adopting the use of graphic and diagrammatic presentation—a mode of illustration which should appeal more readily to the eye and to the understanding than the juxtaposition of mere numerals. This form of presentation has of late years gained rapidly in popularity, and has been freely used by agricultural writers on the Continent and in America. But it was not in vogue in the earlier days of Lawes and Gilbert, and the latter could never bring himself to approve of or to appreciate the utility of graphic methods—graphic methods, that is to say, which were symbolic, as apart from comparative photographs and pictures. The conservatism of Gilbert in this respect undoubtedly detracted from the readiness of intelligibility of many of the Rothamsted memoirs to those whose time for reading was limited. To Gilbert's eye and mind a page of tabulated figures was very easily intelligible, whereas the same results thrown into curves or rectilinear projection appealed little to him until he had translated them into numerals—thus reversing the mental habit of the student trained in the more modern school. It is true that Professor Armstrong, for the purpose of the delivery of his third series of American Lectures, constructed a valuable series of curve diagrams illustrative of the results of the continuous field experiments; but these have not yet been presented in published form. This, therefore, is the first time that anything like free diagrammatic representation of the Rothamsted work has been provided for the general reader. In the present book, which, after all, is but a summary, graphic illustration is, of course, necessarily confined to some of the more striking and salient facts, but it must be regarded as a valuable feature.

To the busy student and to the ordinary agricultural reader, the greatest service rendered by the author is perhaps that furnished in the "Practical Conclusions" appended to each chapter, relating to the department of work to which it is devoted. Some of these conclusions are, it is true, to be found embodied in the original memoirs, but by no means all of them. Mr Hall has evidently devoted very diligent labour to the digestion and assimilation of the material at his disposal, and has given in succinct form the valuable product of the metabolic mental process to which he has subjected it. By way of further appendix to each chapter he also gives, for the sake of those who wish for fuller details, a complete table of reference to the various original memoirs bearing upon the work dealt with in the chapter; and at

the end of the book there is a complete list, not only of the 134 publications which have directly emanated from Rothamsted, but also of 19 papers by other investigators dealing with Rothamsted material, and of 16 other publications dealing with the experiments from one point of view or another.

Lastly it may be added that the book is well got up and printed in large, legible type, on good paper. It is a book which no agricultural teacher will be able to afford to dispense with, and every serious student of agriculture will do well to provide himself with a copy of it.

BERNARD DYER.